

## PHYS 493L

Call #28340

Monday and Wednesday 1400-1650 hr

Room P&A 116

Instructor: Paul R. Schwoebel

Physics and Astronomy Building Room 122

Phone: 277-2616

E-mail: kas.unm.edu

Office hours: By appointment

**Text (optional):** *Building Scientific Apparatus*, 3rd edition, by John Moore *et al.*, (Cambridge University Press, 4<sup>th</sup> ed. 2009) Some reading in this book will be required. Other reading material will be recommended as it pertains to a particular lab element.

**Purpose:** Senior Lab will expose students to the diverse experimental techniques required of a graduate student or professional scientist. These techniques will be developed with the hands-on experience gained through a series of experiments that each require multiple class sessions. These experiments will involve holography, elementary particle decay, Doppler shifts, interference phenomena, and gas discharges. The student will be exposed to a variety of important techniques including interferometry, precision timing and coincidence techniques, particle detection, and sensitive velocity measurements. The laboratory will also include an element devoted to elementary aspects of machine shop practice and an element in which the student participates in the development of a new experiment that will be come a permanent addition to the Senior Lab.

**Grading:** Grades will be based on your performance in the laboratory, such as thorough, complete laboratory notebooks, experimental analysis, and laboratory reports. In addition, each student will be given a one-half hour oral final exam. Laboratory performance and the oral exam will be, respectively, 85% and 15% of your final grade. Attendance is required. You will need to complete four laboratory elements that must include laboratories 1 and 2. Laboratory 3 is strongly recommended and can only be taken following completion of Laboratory 1. The time required to complete a lab element will vary depending on the particular lab; however, plan to spend roughly four weeks of class sessions on each. Lab reports will be turned in for grading within 2 weeks of their completion. If experiments are performed with a partner, each student should keep their own laboratory note book and write their own laboratory reports.

**Laboratory Reports:** Use the standard format for laboratory reports.\*

1. Abstract
2. Introduction
3. Theory
4. Experimental Apparatus
5. Results
6. Discussion & Conclusions
7. References (References are to be to peer reviewed journal articles or books)

Reports should appear as they would in a scientific journal, with graphics embedded in the text.

\*The write-up for Laboratory 3 has some unique requirements as specified in the manual for Laboratory 3.

## **493L: LABORATORY SAFETY**

### ***Department of Physics and Astronomy University of New Mexico***

Elements of this laboratory class pose certain hazards. No instructions can substitute for common sense. If you are unclear about something ask the instructor or TA. Safety topics include: Machine Shop Safety, Laser Safety, High Voltage Safety, and Radiation Safety. Safety rules and guidelines are designed to reduce the possibility of accidents in routine situations. In a research laboratory where much equipment is custom made there is no routine, and there is no safety rule or policy that can substitute for an intelligent and careful handling of the equipment. The following notes are intended to make you aware of the risks of working in the Senior and Optics Laboratories.

### **Machine Shop Safety**

Some basic directions are given in the lab write up. Duplicate and additional items are listed below:

- Never work alone in the shop.
- Safety glasses must be worn in the shop at all times.
- Do not enter the shop with bare feet, sandals, slippers, or open toed shoes.
- Tie back long hair.
- Do not wear loose clothing or jewelry.
- Maintain a clean work area.
- Do not touch chips while the machine is operating.
- Do not leave chuck keys in chucks.
- Secure all work (clamp in vice, chuck, etc.).

### **Laser Safety**

For a complete introduction to laser safety see:

<https://www.osha.gov/SLTC/laserhazards/>

The American National Standard Institute (ANSI) has classified lasers according to what they perceive as hazard level. Class IIIb and class IV lasers are considered as hazardous. The HeNe lasers used in the experiments you will be doing typically will not cause permanent eye damage, however, it is good practice to:

- Never look directly at the beam of the laser.
- Keep the laser beam in one horizontal plane close to the table.
- Never bend down to the table level.

We have purposely chosen to have the optical table surfaces as low as possible which reduces the chances of having your eyes at the beam height. Low chairs are not allowed in the lab. Sitting accommodations are limited to high stools.

### **High Voltage (& Line Voltage) Safety**

You should supplement the following general electrical safety description with reading at:

<http://www.osha.gov/SLTC/electrical/index.html>

The following guidelines are to protect you from potentially deadly electrical shock hazards as well as the equipment from accidental damage. Note that the danger to you is not only in your body providing a conducting path, particularly through your heart. Any involuntary muscle contractions caused by a shock, while perhaps harmless in themselves, may cause collateral damage due to contact with sharp edges and points

inside various things like stamped sheet metal shields and the cut ends of component leads. In addition, the reflex may result in contact with other electrically live parts.

- Don't work alone because in the event of an emergency another person's presence may be essential.
- Always keep one hand in your pocket when near a line-powered or high voltage system.

### **Radiation Safety**

For a complete introduction to radiation safety see: <http://www.osha.gov/SLTC/radiation/>

Several types of radioactive sources will be encountered in the laboratory. Sources you will use in this laboratory are sealed, low activity sources and therefore present no health issues. NEVER eat, drink, or smoke in the laboratory. Wash your hands at the conclusion of each laboratory session. Sealed gamma ray sources having activities of ~ 1  $\mu\text{Ci}$  can be handled with your fingers. For sealed and unsealed source of roughly 10  $\mu\text{Ci}$  or greater use tongs or other devices - Do not handle directly.



**Certification:** *Return this signed statement to the instructor: I have read and understood the document on laboratory safety for Physics 493L and agree to follow these rules when in the laboratory.*

Your Name Printed: \_\_\_\_\_

Signature: \_\_\_\_\_

Date: \_\_\_\_\_

# LAB 1: Mechanical Practices in Experimental Science

Paul R. Schwoebel and Anthony Gravagne

## Purpose

Introduce the student to mechanical practices used in the design and construction of scientific apparatus through exposure to mechanical drafting and the fundamental operations performed in a machine shop

## Reading Assignment

Chapter 1: *Building Scientific Apparatus*, 3rd edition, by John Moore, Christopher Davis and Michael Coplan (Perseus Books, Cambridge MA, 2003) on reserve in the Centennial Library. Familiarity with the material in Chapter 2 is useful for future reference.

## Background

The experimental scientist must routinely design and construct scientific apparatus in order to conduct research. Advanced undergraduate and graduate students in the sciences typically have an introductory electronics class/lab. Often, however, students are not introduced to the mechanical aspects of designing and constructing scientific apparatus until after they begin their graduate research. The student's research career is greatly facilitated if they acquire the proper foundations in these mechanical practices as an undergraduate.

The mechanical aspects of building scientific apparatus involve conceptualizing the requirement, producing a mechanical drawing that defines the apparatus to fulfill that requirement, and fabricating the apparatus to the necessary specifications. As an advanced undergraduate or graduate student you will often be required to accomplish all of these tasks. As a practicing scientist, most often you will perform tasks one and two and submit task three to a professional machine shop. In either case, understanding the basic principles of metal working, glass blowing, and materials joining will aid you in making mechanical drawings to communicate your needs and designing apparatus to fulfill these needs.

## Mechanical Drawing

The book, *Building Scientific Apparatus*, describes the basics of mechanical drawing. More complete treatments<sup>1</sup> can be consulted as your skill levels and needs grow. Modern mechanical drawing is done with the aid of computer programs, referred to as Computer-Aided Drafting (CAD) programs, developed specifically for this task. The limited drawing required for this module will only require pencil, graph paper, a scale, a right triangle, and a compass. Feel free to use computer software to make the drawing if you have some available.

## Shop Safety

The first class session will be spent in the shop actually applying some of the fabrication techniques about which you have been reading. Of utmost importance is your safety in the shop. While you are working in the shop it is **REQUIRED** that you:

1. Wear safety glasses at all times
2. Do not wear open-toe shoes such as sandals or flip flops
3. Secure or tie back loose clothing and long hair
4. Remove all jewelry, especially includes rings, watches, and necklaces
5. Only use brushes to remove metal chips from machines
6. Do not use compressed air to clean yourself or the machines
7. Do not use earbuds, iPods, cell phone or other portable devices
8. Do not use machine tool practices that are not approved by the instructor
9. Focus on the work you are doing
10. Do not work in the shop while under the influence of drugs or alcohol. This includes any prescription drugs which could cause drowsiness, lightheadedness, or disorientation.

If you have a question it is much better to ask the shop personnel for help than to proceed with an operation with which you are unfamiliar.

Appended is a form to read and sign acknowledging you have read and understood the aforementioned safety rules. Give the signed form to the shop foreman on your first day of the Mechanical Practices Lab.

## Machine Shop Practices

During the first class period you will go to the machine shop and be introduced to the basic equipment by one of the machinists. Over the course of the remaining 4 weeks under the machinist's supervision you will then each fabricate a fun two-slider hand-crank device, of which a 3D CAD drawing is shown below. A mechanical drawing of the hand-crank device assembly and the parts you will fabricate is also appended to this write-up. Print out hard copies of these drawings and bring them with you to the first lab period so you can refer to them while in the shop. Drawings for all parts except two are supplied. You will be responsible for making a complete machine drawing of: 1) The brass knob - for which you will need to include critical dimensions such as major and minor diameter of the 3/8-16 UNC 2A thread and 2) The brass nut which is a 3/8-16 hex jam nut. Use the drawings for the other parts and the *Building Scientific Apparatus* text on reserve in Centennial Library as guides on how to make the drawing of the knob and nut. Refer to the *Machinery's Handbook*,<sup>2</sup> also on reserve in the Centennial Library, for the necessary dimensions and tolerances of the nut and thread on the knob. Complete these drawings and have your instructor check them by no later than the beginning of the 3<sup>rd</sup> class period.

Fabrication of the hand-crank device will require you will carry out many of the most important operations done in the machine shop using the lathe and milling machine; the machines on which the majority of the work in a machine shop is performed. Completion

of the hand-crank will require most of the remainder of this laboratory module. During this time basic joining processes such as soldering and welding will be demonstrated so that you are familiar with these techniques.

Submit your completed hand-crank to the instructor for examination. If the parts are within tolerance you will have just completed your introduction to mechanical practices in experimental science. You can keep the hand-crank device.

## **REFERENCES**

- 1) *Technical Drawing*, by F. E. Giesecke et al., 12<sup>th</sup> edition (Prentice Hall, 2002)  
ISBN: 0130081833.

This is an updated version of a book that has been a classic in the area for 60 years.

- 2) *Machinery's Handbook* by Erik Oberg et al, 26<sup>th</sup> edition (Industrial Press, 2000)  
ISBN: 0831126663 (CD ROM and Cloth).

This book has a wealth of information and is a standard reference in the metal working industry.

**Senior Lab Machine Shop Class**

Name: \_\_\_\_\_

**Spring Semester, 2015**

**Revised 1/15/2014**

**SAFETY RULES:**

**Please initial each item**

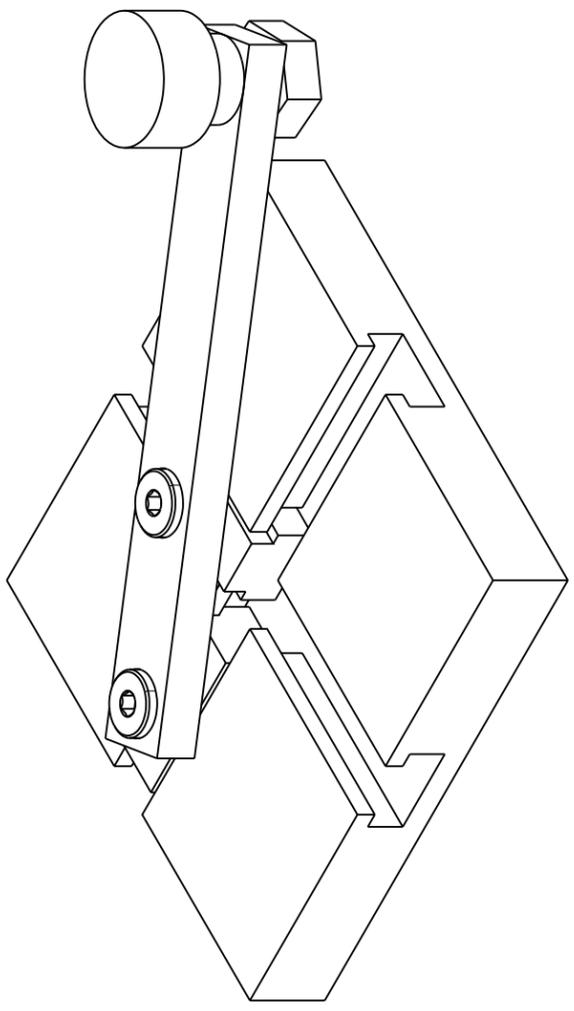
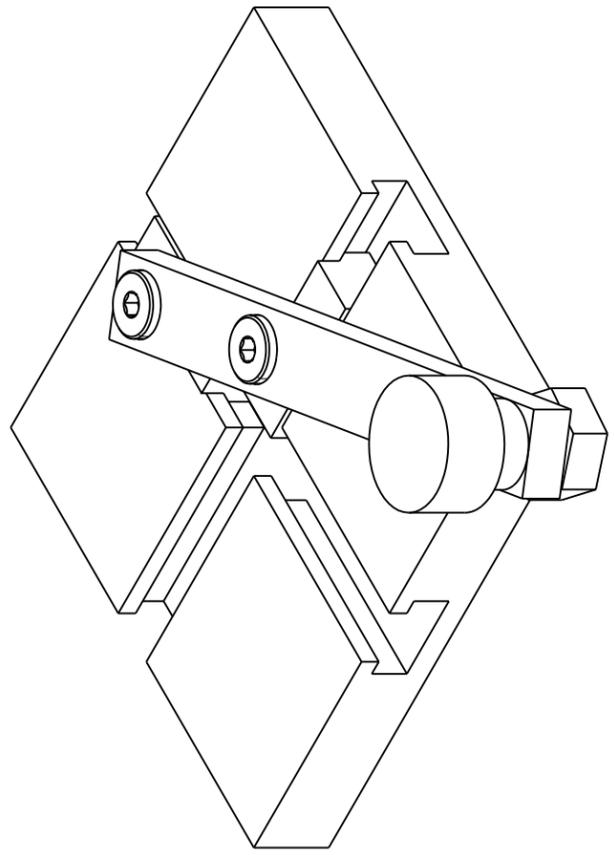
- 1.) Wear safety glasses in the shop!
- 2.) No open-toe shoes such as sandals or flip flops
- 3.) Loose clothing and long hair MUST be secured and/or tied back
- 4.) All jewelry must be removed or tucked away – this especially includes rings and watches
- 5.) Only use brushes to remove metal chips from machines
- 6.) Do not use compressed air to clean yourself or the machines
- 7.) No earbuds, iPods, cell phone use or other portable device use
- 8.) Don't invent your own techniques
- 9.) Pay attention to your work and remain focused
- 10.) No work in the shop while under the influence of drugs or alcohol. This includes any prescription drugs which could cause drowsiness, lightheadedness, or disorientation.

I have read and agree to abide to the above rules while in the machine shop. I understand that these rules are for the safety of ALL PERSONNEL in the shop.

Signature: \_\_\_\_\_

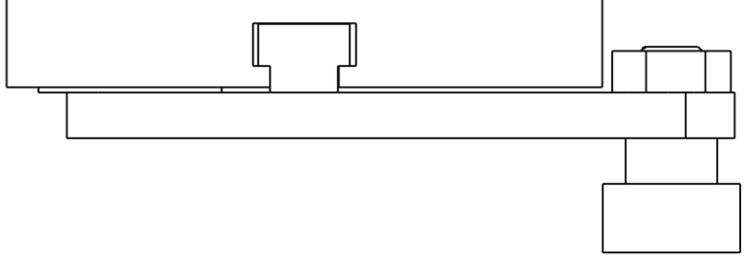
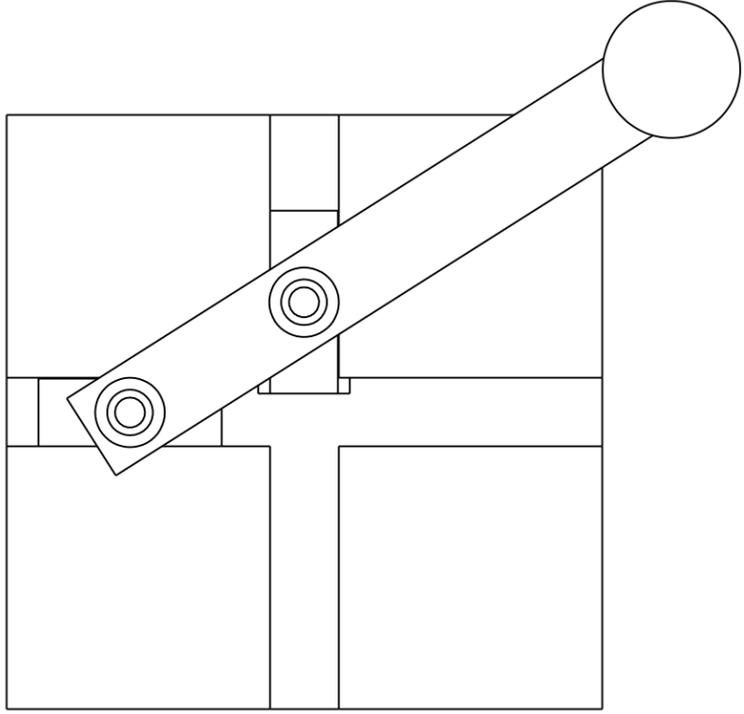


REVISIONS				
ZONE	REV	DESCRIPTION	DATE	APPROVED

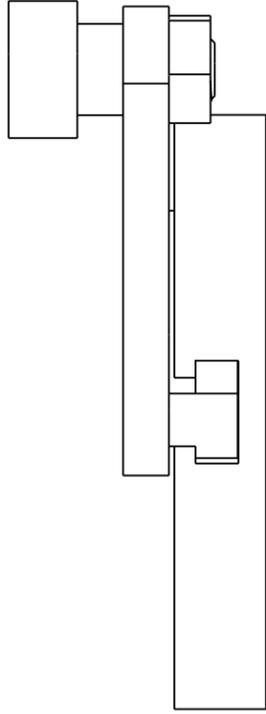


 <b>THE UNIVERSITY of NEW MEXICO</b> Department of Physics & Astronomy Machine shop 1919 Lomas Blvd. NE Albuquerque, NM 87131 505-277-4327	DRAWN <b>A GRAVAGNE</b>	DATE 1/5/15	<b>TWO SLIDER HAND CRANK</b>	
	CHECKED	MATERIAL	QTY	3D VIEW
			SIZE <b>B</b>	FSCM NO. _____ DWG NO. _____
			SCALE NTS	SHEET 3D





NOTES:  
 1. BRASS SLIDERS AND SHOULDER BOLTS SUPPLIED BY MACHINE SHOP  
 2. ASSEMBLE HANDLE TO SLIDERS USING SHOULDER BOLT 1/4" DIAM SHOULDER,  
 1/8" SHOULDER LENGTH, 10-32 THD. MCMASTER #94035a531



 THE UNIVERSITY of  
 NEW MEXICO  
 Department of Physics & Astronomy  
 Machine shop  
 1919 Lomas Blvd. NE  
 Albuquerque, NM 87131  
 505-277-4327

DRAWN  
 A GRAVAGNE  
 CHECKED  
 MATERIAL  
 QTY  
 1EA ASSY PER STUDENT

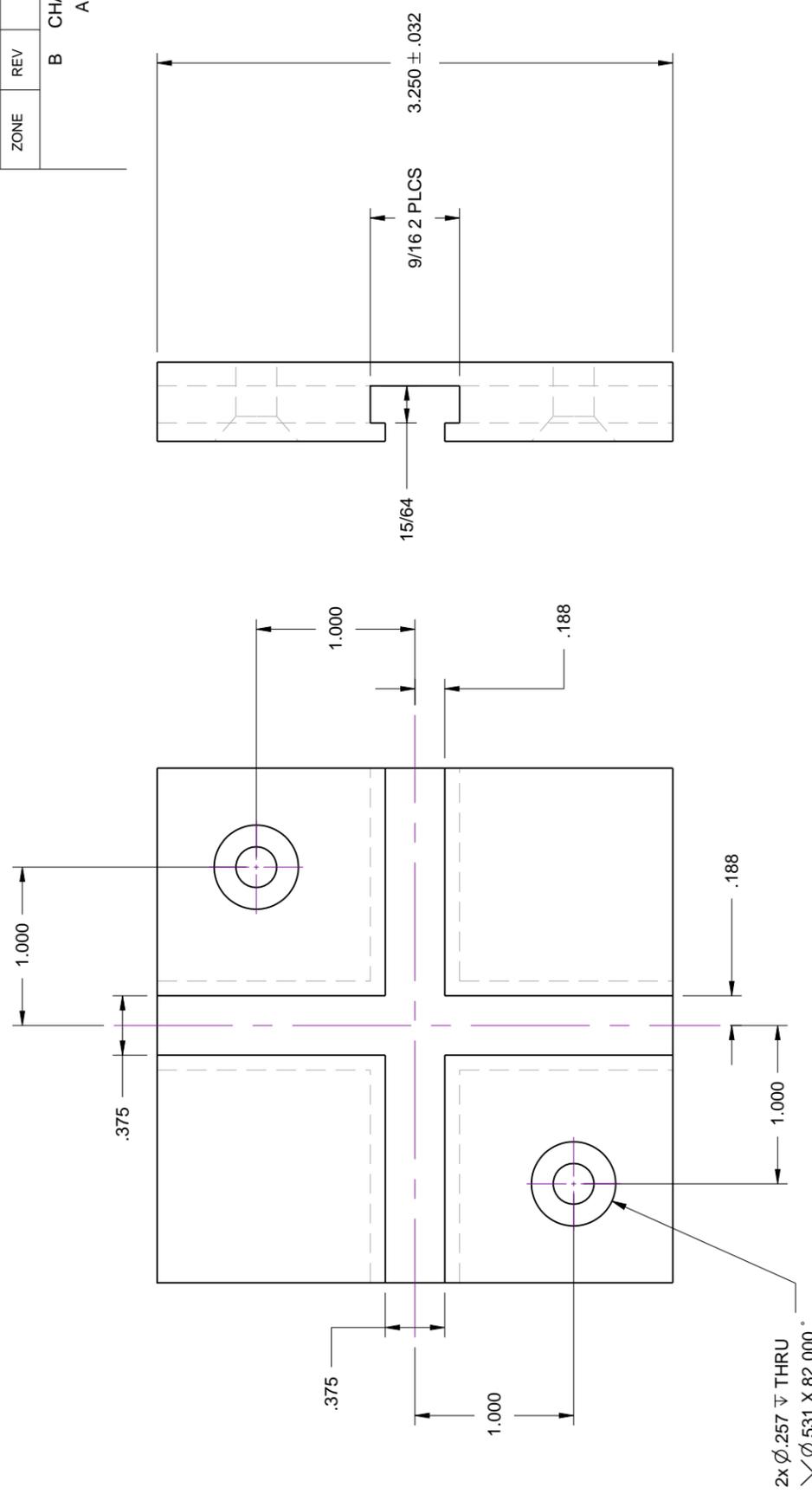
DATE  
 1/5/15  
 SCALE  
 1:1

TWO SLIDER HAND CRANK  
 ASSEMBLY VIEW  
 SIZE  
 B  
 FSCM NO.  
 DWG NO.  
 SL-SC15-4  
 REV  
 SCALE  
 1:1  
 SHEET  
 4 OF 4

REVISIONS				
ZONE	REV	DESCRIPTION	DATE	APPROVED



REVISIONS			
ZONE	REV	DESCRIPTION	DATE
	B	CHANGED TOLERANCE ON ODS, DIMS FROM CENTER ADD C'SUNK MOUNTING HOLES	1/5/15



- NOTES:  
 1. ALL DIMENSIONS IN INCHES  
 2. ALL DIMENSIONS ± .005" UNLESS NOTED  
 3. BREAK ALL EDGES AND SHARP CORNERS

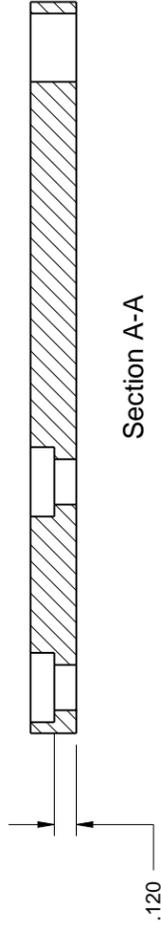
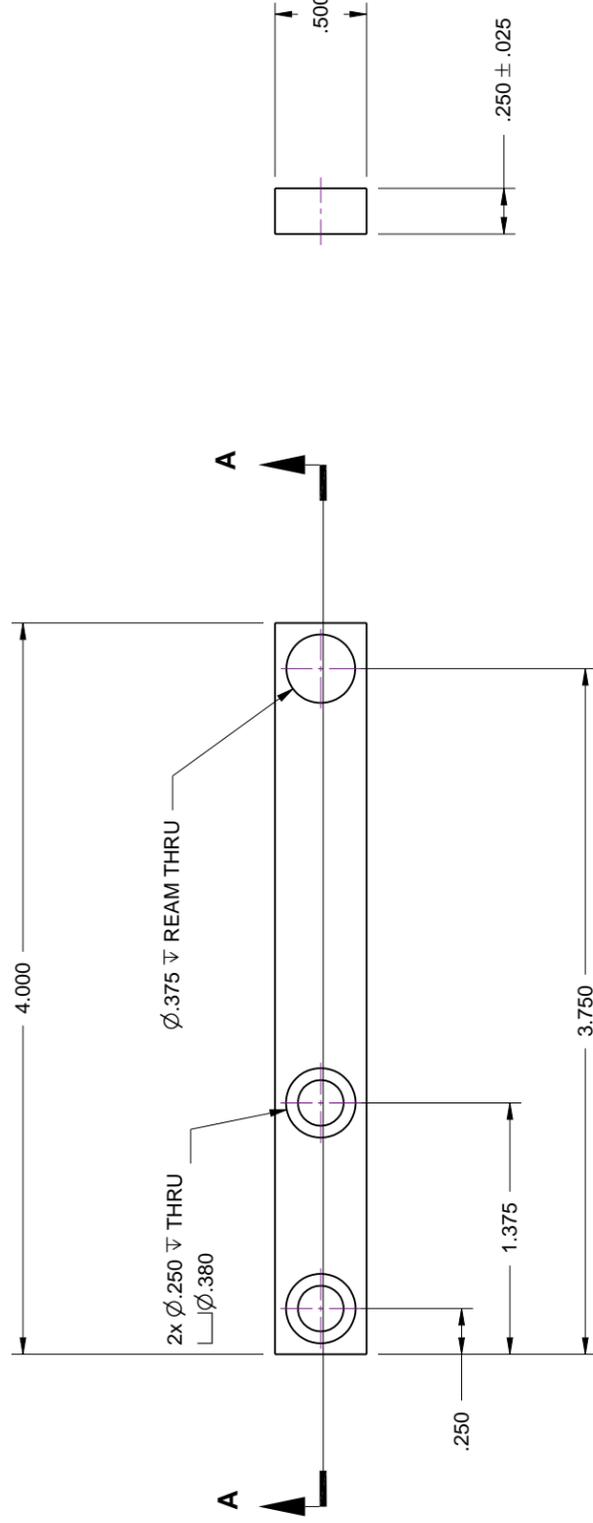
 <b>THE UNIVERSITY of NEW MEXICO</b> Department of Physics & Astronomy Machine shop 1919 Lomas Blvd. NE Albuquerque, NM 87131 505-277-4327		DRAWN A GRAVAGNE CHECKED	DATE 1/5/15	<b>TWO SLIDER HAND CRANK</b>	
		MATERIAL ALUM 6061		BASE PLATE	
		QTY 1EA PER STUDENT		SIZE <b>B</b>	FSCM NO. _____
				DWG NO. SL-SC15-1	REV <b>B</b>
				SCALE 1:1	SHEET 1 OF 4





REVISIONS			
ZONE	REV	DESCRIPTION	DATE
	B	ARM LONGER, WIDER, END HOLE CHG TO Ø.375	1/5/15

B ARM LONGER, WIDER, END HOLE CHG TO Ø.375 1/5/15



Section A-A

- NOTES:
1. ALL DIMENSIONS IN INCHES
  2. ALL DIMENSIONS  $\pm .005"$  UNLESS NOTED
  3. BREAK ALL EDGES AND SHARP CORNERS


**THE UNIVERSITY of NEW MEXICO**  
 Department of Physics & Astronomy  
 Machine shop  
 1919 Lomas Blvd. NE  
 Albuquerque, NM 87131  
 505-277-4327

DRAWN	A GRAVAGNE	DATE	1/5/15
CHECKED			
MATERIAL	ALUM 6061		
QTY	1EA PER STUDENT		

TWO SLIDER HAND CRANK			
HANDLE ARM V1.5			
SIZE	FSCM NO.	DWG NO.	REV
B		SL-SC15-2	B
SCALE	1:1	SHEET	2 OF 4





## LAB 2: Experiments in Nuclear Physics

John A. J. Matthews, Michael P. Hasselbeck, and Paul R. Schwoebel

### Purpose

Introduce the student to some of the basic techniques and approaches used in nuclear and particle physics.

### Reading Assignment

Reading required as per references in text of experiment.

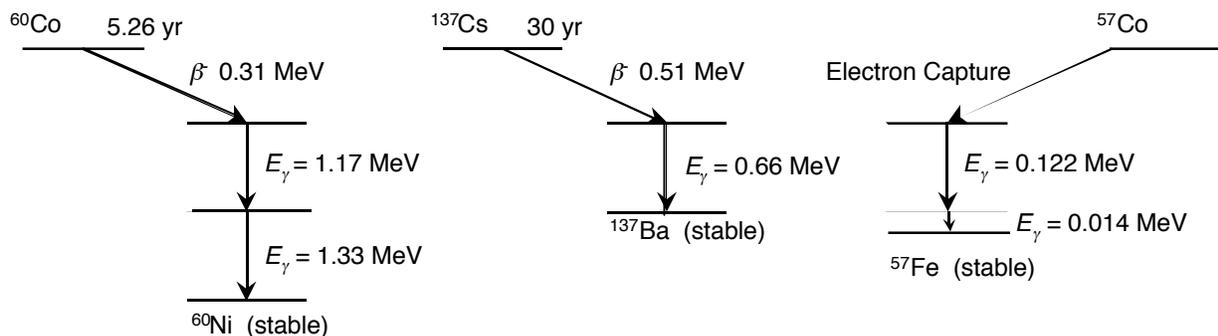
### Preface

This laboratory is divided into two sections. The first section is an introduction to gamma-ray spectroscopy.  $\gamma$ -ray spectroscopy is of both fundamental and applied interest. The techniques introduced in  $\gamma$ -ray spectroscopy will be expanded upon and used in the second section to measure the mean-life of the muon. The mean life of the muon is directly related to the fundamental strength of the Weak Nuclear Force; one of the four fundamental forces in nature.

### Part 1: Gamma-Ray Spectroscopy

#### Introduction

The decay of many radionuclides involves the emission of  $\gamma$ -rays. Processes that leave the daughter in an excited state can lead to gamma emission. Alpha emission and beta emission precede gamma decay in the natural radionuclides. For example, there can be a large difference between the nuclear spin of the ground states of the parent and the daughter. Then the beta transition directly to the ground state of the daughter is forbidden and therefore most of the transitions leave the daughter in an excited state. Decay schemes for some radionuclides are shown below.



Often the half-life of the parent is very long relative to the half-life of the daughter. In this case gamma decay is in transient equilibrium with the decay of the parent and the  $\gamma$ -ray intensity falls off with the half-life of the parent. This is the reason it is customary to name the parent as the  $\gamma$ -ray source.

$\gamma$ -ray spectroscopy has a number of important uses in the applied sciences. For example, it can be used to identifying much of the elemental composition of an unknown sample. To do this the unknown sample is irradiated with neutrons which makes the sample radio active. This is so-called ‘neutron-activation’. One can then measure the  $\gamma$ -rays (and  $\beta$ -rays) and sample half-life to determine the constituents and their relative concentrations. This technique is used in the petroleum industry and areas of geology, medicine, and criminology, to name a few.

To learn about  $\gamma$ -ray spectroscopy and standard instrumentation used in nuclear physics you will:

1. Observe  $\gamma$ -ray energy spectra,<sup>1</sup>
2. Identify the processes taking place,<sup>2-8</sup>
3. Complete an energy calibration of the apparatus. <sup>9, 10</sup>
4. Determine the identity of an unknown isotope.
5. Determine the attenuation coefficients of  $\gamma$ -rays as a function of  $\gamma$ -ray energy.<sup>2, 10, 11</sup>

**Procedure:**

A radioactive  $\gamma$ -ray source is placed near a NaI(Tl) scintillation detector. The NaI(Tl) absorbs the  $\gamma$ -ray and gives a light burst proportional to the amount of energy absorbed. The light is converted into electrons by a photocathode mounted on the input of a photomultiplier tube (PMT). The PMT is interfaced by the PMT base to a high voltage power supply and amplifier (or preamplifier plus amplifier). The PMT outputs a current pulse which is proportional to, and much greater than, the initial photoelectron current. Finally a multichannel analyzer (MCA) digitizes the pulses and stores a histogram of the number of pulses versus pulse amplitude. This is shown schematically in Fig. 1.

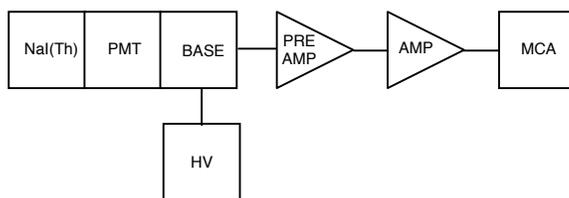


Fig. 1: Schematic drawing of the electronics for  $\gamma$ -ray spectroscopy. The NaI(Th) scintillator crystal, PMT, and PMT Base are a single unit. The high voltage applied to the base is negative and less than 1500 V. The preamp and amplifier are typically Nuclear Instrumentation Modules (NIM) powered by a NIM crate. The MCA is a stand alone unit.

**1. Observe  $\gamma$ -ray energy spectra, identify the processes taking place, energy calibration the apparatus, and determine the identity of an unknown isotope.**

The UCS 30 MCA you will be using has an integral high voltage supply. Following the manual (Appendix 3) for the MCA connect it to the high voltage input for the PMT. Using the <sup>137</sup>Cs source, observe the output from the anode output of the PMT base on an oscilloscope using 50  $\Omega$  termination. The pulse will be negative. Set the high voltage on the PMT so that the pulses are > 50-100 mV. Typically ~ *positive* 1200 V is adequate high voltage; **do not exceed +1500V**. Before continuing it is instructive to see the  $\gamma$ -ray line(s) directly on the oscilloscope. Each line will appear as a brighter *band*. To see this you will need to get the correct trigger polarity: negative if you take the signal from the anode output of the PMT base or positive if you take the

signal from the dynode output of the PMT base. You will also need a sweep rate that is matched to the time response of the NaI(Tl) detector. Once you find the signal, vary the high voltage (modestly) to see how the signal magnitude varies with applied high voltage. At this point you may want to determine what voltage change will cause a doubling of the signal amplitude!

The UCS 30 MCA also has an integral preamp and amplifier. Following the manual (Appendix 3) for the MCA connect it to the output of the PMT. For simple applications you should set the MCA to accumulate/display the maximum number of channels. The final choice of high voltage and amplifier gain settings should place the highest energy  $\gamma$ -ray line near the upper end of the MCA range. As different combinations of high voltage and amplifier gain will result in the same amplitude signal you may want to investigate which combination gives you the sharpest signal: i.e. the narrowest line for a fixed signal amplitude. At this point you should also accumulate  $\gamma$ -ray spectra from the  $^{60}\text{Co}$  source to learn the range of  $\gamma$ -ray energies and the number of distinct lines. Then you should consider building a cave, from lead bricks, to shield the NaI(Tl) detector from extraneous (i.e. background)  $\gamma$ -rays. Where does this background come from? You should also experiment with the distance between the source and the front of the NaI(Tl) detector. Does this make any discernable difference other than count rate? A good rule of thumb is to place the source at least 2 detector diameters from the detector. Why? The effective solid angle of the detector is then  $(\pi r^2)/4\pi d^2$ , where  $r$  is the detector radius and  $d$  is the source-to-detector distance. With your optimal setup you should accumulate a spectrum from each of the  $\gamma$ -ray sources. Do the spectra look different from your first spectra? How and why? Do the spectra look like the text book spectra? Identify as many of the features and lines as you can. Now take individual spectra for a couple sources such as the  $^{137}\text{Cs}$  and  $^{60}\text{Co}$ . You may also want to try the  $^{57}\text{Co}$  source if it is not too old. Do this in as short a time period as is possible. Repeat to be sure that your peaks have not drifted! Determine the channel numbers for the center of each  $\gamma$ -ray line. If the DAQ electronics and the MCA are linear there should be a linear relation between peak channel number and  $\gamma$ -ray energy. To check this make a plot of channel number versus energy. Are the points in a line? Does the curve go through (0,0) or is there an offset? To what energy does channel 1 correspond? Now get an unknown  $\gamma$  source from the instructor. Using references<sup>2, 10</sup> identify the unknown source.

Other issues you should consider include:

Do you have a circuit diagram including all equipment device types/numbers, SETTINGS, etc. so that you could easily rebuild your setup. Have you sketched pulse shapes at different places in the circuit? What should you check for when looking at pulse shapes? What change in phototube high voltage results in a 100% increase in the observed  $\gamma$ -ray pulse heights (i.e. channel number in MCA)?

To a first approximation the gamma ray line-width, that is its Full-Width at Half-Maximum (FWHM) is  $2.35\sigma$ , and related to the statistical fluctuations in the number of photo-electrons,  $N_e$ , that are collected from the photocathode of the phototube. In turn  $N_e \propto E_\gamma$ , thus:

$$\sigma/E_\gamma = 1/\sqrt{N_e} \propto 1/\sqrt{E_\gamma}$$

Thus this ratio measures  $N_e$ . Check this by plotting  $(E_\gamma/\sigma)^2$  versus  $E_\gamma$ . If the plot is linear then our approximation was valid; that is there should be an essentially constant  $\gamma$ -ray energy required per observed photo-electron. What is the average  $\gamma$ -ray energy/photo-electron in your experiment? The inverse question is how many photoelectrons result from a 1 MeV  $\gamma$ -ray?<sup>12</sup> Does this number make sense?

$\gamma$ -ray (i.e. photon) cross sections for interacting with the NaI(Tl) are rather small in the energy range of a few hundred keV to  $\sim$ MeV. The photon interaction processes include the photoelectric effect, Compton scattering and pair production. What photon cross section is most directly related to the total conversion of the  $\gamma$ -ray to visible light in the energy range of this experiment? Is this the dominant cross section at these energies? What is the dominant photon interaction? Does this dominant process result in events in the observed  $\gamma$ -peaks? If not how do events get to be in the peak?

## 2. Measure $\gamma$ -ray attenuation coefficients:

Just as  $\gamma$ -rays interact with the NaI(Tl) to be detected or with lead shielding to reduce background counts,  $\gamma$ -rays interact with all matter. The physical processes include the photoelectric effect, Compton scattering and pair production as noted above. These cross sections are combined (in a variety of ways depending on the precise definition) into an absorption or attenuation coefficient,  $\mu$ . Thus following a distance,  $X$ , an initial number of  $\gamma$ -rays,  $N(0)$ , is attenuated to a final number,  $N(X)$ :

$$N(X) = N(0) e^{-\mu X}$$

Because the photon cross sections change rapidly with energy and depend on the absorber material's nuclear charge, it is interesting to measure  $\mu$  at different energies and for more than one absorber material.

To measure the energy dependence of  $\mu$ , start with the  $^{137}\text{Cs}$  source and the MCA. To know  $N(0)$  for each  $\gamma$ -ray line, you need to take (and fit) a MCA spectra with no absorber and for a known "live-time" interval. Then take additional spectra with different thickness of absorber and for different types of absorber. Copper and lead are available. Plot  $N(X, E_\gamma)$  versus absorber thickness,  $X$ , as you accumulate the data. Remember to include the statistical uncertainty in each measurement,  $\delta N$ , in your plot:<sup>13</sup>

$$\delta N = \sqrt{N}$$

Are your statistics sufficient such that  $\delta N \ll N$ ? If not, accumulate spectra for longer periods of time. If spectra are accumulated for different time intervals how do you record them in one plot? Have you taken spectra for enough absorber thicknesses to measure the  $X$ -dependence of  $N(X)$  at small- $X$  where  $N(X) \sim N(0)$ , and also at large  $X$  where  $N(X) \ll N(0)$ . Why is this important? Now try the  $^{60}\text{Co}$  source. Should your steps in absorber thickness be the same at different  $\gamma$ -ray energies and/or for different absorbing materials? Why or why not?

Do you need to correct for the NaI(Tl) efficiency,  $\epsilon$ ? Why or why not? Because you expect an exponential decrease with absorber thickness you should plot your data on a semi-log plot. Do your results agree with the exponential dependence on absorber thickness? Do your results agree with smaller values for  $\mu$  at larger  $\gamma$ -ray energies? If the answer to either of the last two questions is no, then you may want to reconsider the *geometry* of your experimental setup. Can the absorber provide a scattering path for  $\gamma$ -rays not initially directed at the NaI(Tl) detector to scatter into the detector? How can you minimize this experimental problem? Once you have a reliable experimental geometry and analysis procedures, take sufficient spectra to measure  $\mu$  at several energies and for at least two absorber materials. How do your results compare with tabulated values for  $\mu$ ?

## Part 2: Measurement of the Mean Life of the Muon

## Introduction

The muon<sup>14</sup> is an elementary particle indistinguishable from the electron except that its mass is  $\sim 200$  times greater. Muons are produced primarily from the decays of charged pions,  $\pi^\pm$ , which are themselves produced (copiously) in extensive air showers caused by cosmic rays. Primary cosmic rays cover the spectrum from protons to intermediate mass nuclei ( $<$  iron). The primary cosmic rays interact with nuclei in the atmosphere creating large numbers of charged and neutral  $\pi$  mesons. These subsequently interact or decay. Depending on the energy of the initial cosmic ray, millions or billions of secondary particles can be produced. This is called an extensive air shower.

Generally the neutral mesons,  $\pi^0$ , decay before interacting. Depending on their energy, the charged pions may interact with nuclei in the atmosphere or may decay,  $\pi^\pm \rightarrow \mu^\pm + \nu$ , to charged muons and neutrinos. To understand this behavior look up the lifetimes,  $\tau_\pi$ , and masses,  $m_\pi$ , of charged and neutral pions. The average distance they travel (before decaying) depends on their energy,  $E_\pi$ , and is given by:

$$\text{Distance} \sim (E_\pi/m_\pi c^2) c t$$

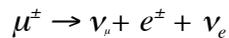
where  $c$  is the speed of light. What are typical distances if  $E_\pi = 10^9$  eV or if  $E_\pi = 10^8$  eV? If this distance is large then it is likely the  $\pi$  interacts before it decays.

Unlike pions, muons do not interact strongly. Thus to first order they will decay before they interact. The distance a typical  $E_\mu = 10^9 - 10^{10}$  eV muon travels is thus:

$$\text{Distance} = (10^9 \sim 10^{10} [eV]) / (105.7 [MeV]) (3 \times 10^8 [m/s]) (2.197 \times 10^{-6} [s]) = \\ 6.24 \sim 62.4 [km].$$

Where the muon mass  $m_\mu = 105.7$  MeV. This distance is sufficiently great that many muons reach the earth surface. In fact at the earth's surface muons are the dominant component of secondary particles from cosmic ray showers. Most of the muons are of modest energy by the time they reach ground level. Thus some will range out, i.e. stop, in a tank of liquid scintillator. The study of the decay of these stopped muons is the basis of this experiment.

Muons decay via the weak interaction similar to the  $\beta$ -decay of free neutrons and nucleons in nuclei:



Because neutrinos only interact via the weak nuclear force, muon decay is one of very few natural processes that only involves the weak interaction. The decay rate is actually a measure of the strength of the weak interaction, much like the electronic charge is a measure of the strength of the electromagnetic interaction.

As with nuclear  $\beta$ -decay the energy ( $E_e$ ) spectrum of the resultant  $e^\pm$  is that for a typical three body weak decay:<sup>1</sup>

$$d\Gamma(E_e)/dE_e = (G_F^2/12\pi^3) m_\mu^2 E_e^2 (3 - 4 E_e/m_\mu).$$

where  $d\Gamma$  is the muon decay rate. If this is integrated over possible electron energies:

$$\Gamma = 1/\tau_\mu = G_F^2 m_\mu^5 / 192\pi^3$$

where  $\tau_\mu$  is the muon lifetime and  $G_F$  is the Fermi coupling constant. The Fermi coupling constant is the fundamental coupling constant of the charge changing weak interaction. Thus a measurement of the muon lifetime provides a measurement of  $G_F$  once the muon mass is known!

A fraction of the muons that reach the earth's surface have just the correct energy to stop in a block or tank of scintillator. As the muons stop they deposit  $\sim 2 \text{ MeV}/(\text{gm}/\text{cm}^2)$  in the scintillator. Because the density of scintillator is  $\sim 1 \text{ (gm}/\text{cm}^3)$ , muons deposit  $\sim 2 \text{ MeV}/\text{cm}$  of path length. This is much greater than the  $\sim 1 \text{ MeV}/\text{cm}$  of typical  $\gamma$ -rays in Part 1 of this lab. Thus these stopping muons result in a pulse of light (in the scintillator) which is easily detected.

Roughly 5% of the  $\mu^-$  will be captured into low Bohr orbits and then interact with the nucleus of the scintillator atoms before decaying. Thus the majority of  $\mu^-$  and virtually all the stopped  $\mu^+$  decay before interacting with electrons or nuclei in the scintillator. Each muon decay results in an electron with a energy up to  $m_\mu/2 \sim 53 \text{ MeV}$  (i.e. neutrinos are essentially massless). These electrons also can result in a pulse of light (in the scintillator) which is also easily detected.

If one starts a clock each time a muon stops, i.e. this defines  $t = 0$ , then for a total of  $N_{stop}$  stopped muons the number of muons remaining at a time  $t$  later is:

$$N(t) = N_{stop} \exp(-t/\tau_\mu).$$

Note: clearly this assumes that muons are not lost due to interactions with the scintillator (see comments above). Process other than weak decays that remove muons will result in a low value for  $\tau_\mu$ . Random accidentals will be flat in time and will result in a high value for  $\tau_\mu$ , unless you analyze your data properly.

The number of muon decays in the time interval from  $t_1$  and  $t_2$  is:

$$\Delta N(\langle t \rangle) = N(t_1) - N(t_2) = N_{stop} \{ \exp(-t_1/\tau_\mu) - \exp(-t_2/\tau_\mu) \} \sim N_{stop} (\Delta t/\tau_\mu) \exp(-\langle t \rangle/\tau_\mu).$$

where  $\Delta t = t_2 - t_1$  and  $\langle t \rangle = (t_2 + t_1)/2$ , and the approximate relation is valid when  $\Delta t \ll \tau_\mu$ . Thus a histogram of the number of the observed decays,  $\Delta N(\langle t \rangle)$ , binned in time bins of width  $\Delta t$ , is predicted to be a simple exponential in  $\langle t \rangle/\tau_\mu$ . A semi-log plot of  $\Delta N(\langle t \rangle)$  versus  $\langle t \rangle$  will have a slope  $-1/\tau_\mu$ .

## Procedure

The muon decay experiment starts with a large tank of liquid scintillator viewed by two phototubes (PMTs). If one PMT is sufficient to trigger on cosmic ray muons and on the electrons from muon decay, why use two PMTs? The basic setup is shown schematically in Fig. 1. As depicted in Fig. 1, the difference between a through going muon and a stopped muon followed by a  $\beta$ -decay, is one pulse versus two pulses.

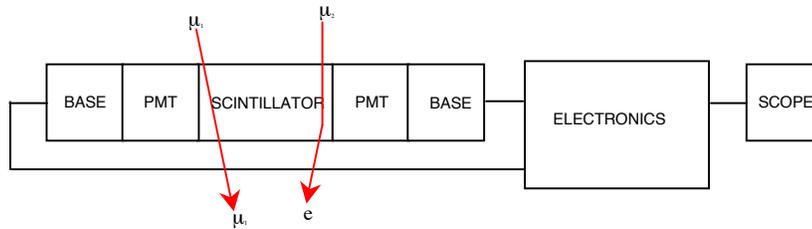


Fig. 1. Schematic setup for muon lifetime experiment.  $\mu_1$  passes through the scintillator losing some energy: A single voltage pulse appears on the scope.  $\mu_2$  stops in the scintillator and decays after time  $t$  to an electron: Two voltage pulses appear on the scope.

You will measure the lifetime of the muon using two different approaches for the ‘electronics’ package shown in Figure 1. The first is based upon Nuclear Instrumentation Module (NIM) electronics. Although no longer routinely used to accumulate the final data in modern particle physics experiments it is often still used to set up such experiments as it allows for oscilloscope validation of each step of the experiment upon which a dedicated board can then be designed, fabricated and used. The second method you will use to measure the muon lifetime is with just such a dedicated board. By making the measurement using both approaches you will see the individual measurements made in nuclear/particle physics via NIM instrumentation and how present day experiments are conducted with dedicated boards.

### 1. NIM Based Measurement

A sketch of a realistic experimental setup is shown in Fig. 2. The PMTs require **negative HV and  $\sim -1500$  V or less** should provide adequate output signals. In practice you need to adjust the HV for each PMT to get approximately the same output signals. Typically the PMT output signals are discriminated with  $V_{threshold} = 30$  mV. Set the discriminator output pulse length to  $\sim 20$  ns. Are the pulse lengths sufficient to allow for the variation in pulse timing between the 2 PMTs and still give a coincidence? Have you adjusted the relative time delay between the two scintillator signals so the signals are in time on average? Set the coincidence unit to require a 2-fold coincidence. The coincidence requires that both PMTs are above threshold to avoid noise triggers or triggers from cosmic ray muons that are clippers.

To monitor and set up your experiment pass signals of interest through the scope; i.e. put the oscilloscope between outputs of interest and the next device in the logic/signal chain.

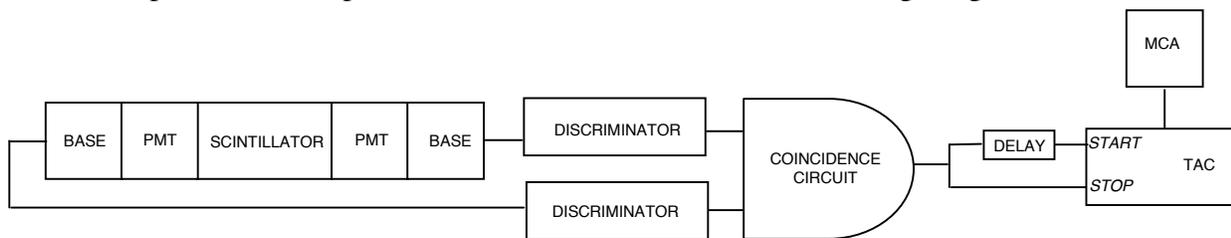


Fig. 2. A practical experimental arrangement for the muon lifetime experiment.

Two outputs are taken from the coincidence unit. One is delayed and used to START the TAC. The other is used to STOP the TAC. For details on how a TAC works see Appendix 1. At first this order appears to be counter intuitive. This is explained by Fig. 3 and by the fact that only when the TAC receives a good START-STOP combination will it produce an output pulse. To

delay the signal to the TAC *START*, use the delay box supplied with the experiment. How much delay should be introduced?

Thus all the events that have a *START* but no *STOP* within the TAC time window will result in no TAC output. For events with a good *START-STOP* combination the TAC output pulse has an amplitude proportional to the difference in time between the *START* and *STOP*. The TAC output signal is analyzed in the MCA. This is the good news. The bad news is that if a second muon passes through the scintillator close in time to first, then the second muon is indistinguishable from a decay electron. This results in a random accidental signal that should be uniform in time and thus produce a flat background. Start to think how you will analyze the data to accommodate this background!

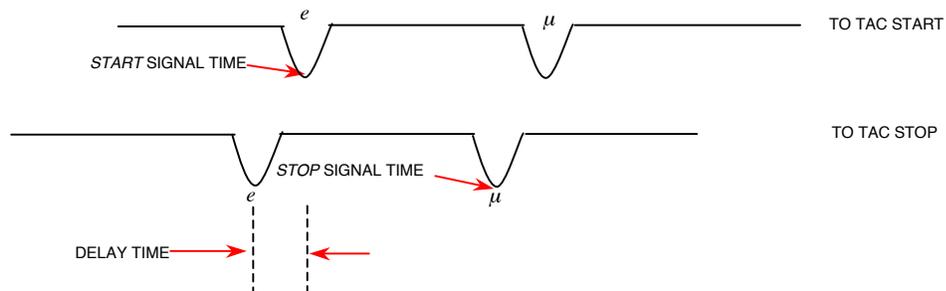


FIG. 3. Sketch of the signals entering the TAC versus time (not to scale in time). The effect of the delay is to cut off the first part of the histogram stored in the MCA. It does not change the exponential nature of the histogram.

Set the time window on the TAC to  $\sim 5-10$  muon lifetimes. Thus the data at large times will be essentially all accidentals. Don't set the time window too long or you will only be studying accidentals. If you have time you should accumulate and analyze data taken with different TAC time windows.

To obtain adequate statistics you will need to run for at least 24 hours. Remember to leave a big **DANGER HIGH VOLTAGE** sign on you apparatus.

The raw data from the MCA is a histogram of counts versus channel number. You need to calibrate the system. That is, you supply a well defined time signal into the TAC/MCA combination to obtain the conversion from channel number to time. This is shown schematically in Fig. 4. Use a pulse generator followed by a discriminator (or simple splitter) to create two *in-time* signals. Put one through a precision delay. Calibrate the full scale of the TAC/MCA. If you take data sets with different TAC time windows you will need to calibrate for each TAC setting. Remember to calibrate the TAC/MCA immediately before or after your data run, i.e. before you inadvertently change something.

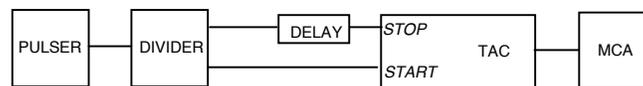


FIG. 4. Arrangement for time calibration of the TAC-MCA.

The recommended technique to analyze the data is to extract a spread sheet file from the MCA to manipulate and fit the data. You will need to correct for background counts. Remember if your time bins become too wide then the simple 1-exponential form is no longer correct. How does

your measurement compare with the world average of  $\tau_e = 2.197 \mu\text{s}$ ?<sup>15</sup> If you agree within 5-10 % you are measuring the Fermi coupling constant to that same precision!

## 2. Dedicated Board Based Measurement

The QuarkNet card was designed and built by engineers at Fermilab in Batavia, Illinois to replace traditional NIM. A single circuit board amplifies PMT signals by 10x and uses voltage comparators for discrimination with adjustable threshold. On-board timing is implemented with CPLD (Complex Programmable Logic Device) via software installed at Fermilab. Photon events are time-resolved with an accuracy of 1.25 ns using a time-digital-converter. A micro-controller interfaces with the control PC using a custom LabVIEW program.

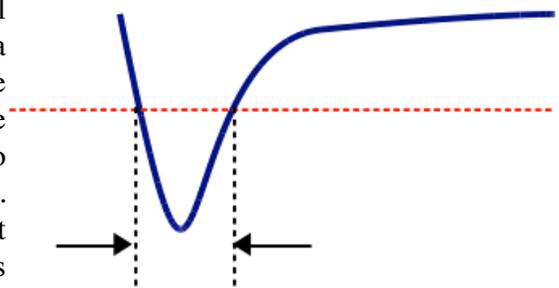
Connect the PMT outputs to two detector input channels on the QuarkNet card. Each channel preamplifier has  $50 \Omega$  input impedance, so if the PMT signals are also being monitored on a parallel oscilloscope the channel input impedance should be set to  $1 \text{ M} \Omega$ . Apply 5 VDC power to the QuarkNet card by plugging the AC adapter into a wall socket. A blinking LED associated with each channel indicates the occurrence of a local trigger. The LEDs can give a rough visual guide to assist in configuration (Note: the digital counter is of little value). Open the LabVIEW program Setup.vi.

**Card Timing:** Triggering can be initiated by either: 1) one pulse from a single PMT or 2) coincident pulses from 2, 3, or 4 PMTs. Coincident triggering is more reliable because it is less susceptible to false signals produced by random background noise. This experiment has two PMTs available to monitor photons in the scintillator tank.

If coincident triggering is used, the time overlap window (coincidence time) must be set. The default value is 40 ns. At the default setting, two PMTs must produce individual pulses that exceed their specified threshold voltage AND occur within 40 ns of each other to create a trigger. If the coincidence time is too short, relatively few card triggers will occur. If it is too long, there is increased probability of false triggers. The oscilloscope display of the pulses can guide this setting. The coincidence time has no meaning in the single trigger configuration.

Once the card triggers, all the detector input channels will record above-threshold photon signals during a specified time (gate width). The proper gate width will depend on the type of experiment being performed. If only the triggering pulse or pulses are to be recorded, the gate width can be relatively short. If muon decay events are of interest, the gate width must exceed the expected muon lifetime by 4 to 5x. Longer than this will introduce noise; a significantly shorter gate will make determination of the decay time difficult.

**Threshold:** Each channel of the QuarkNet card will locally trigger when the amplified PMT pulse exceeds a specified threshold voltage. This is illustrated by the dotted red line in the adjacent figure. Recall that the threshold voltage must be adjusted by 10x compared to the PMT output to account for amplification on the card. Also note that individual channel triggers do not guarantee the gate will open if coincidence triggering has



T: time over threshold

been selected. Simultaneous PMT events as defined by the coincidence time window are required.

The time-over-threshold of an individual pulse can be recorded with a precision of 1.25 ns. This time gives an approximate measure of the integrated power and hence the relative energy in the PMT pulses.

**Setup:** The LabVIEW program Setup.vi helps configure the QuarkNet card. The goal is to set the PMT bias voltage along with the channel thresholds to acquire reliable data counts. The negative-going voltage of the PMT output pulses must be sufficiently above the background noise and at a level where they can be readily discriminated.

Initial setup should be performed with single detection, a gate width of 100 ns, and 100 mV threshold. Negative voltage for all PMT signals is assumed, so the threshold is entered as a positive number. These settings are not critical, but should be a good starting point. The sampling period should be long enough that the count does not vary widely between display updates. Start the program, wait three seconds for the card to initialize, and press the RUN button. Detector counts will be displayed. To change an operating parameter, press PAUSE, make the desired change, then press RUN. The PAUSE button allows parameters to be modified without a complete card reset. As the threshold voltage increases, the count rate should drop. When higher thresholds do not noticeably reduce the count rate, a good operating threshold voltage is identified. Keep the PMT voltage constant and configure the second channel using the same criteria. If adequate thresholds can't be established on both channels, the PMT voltage must be changed.

Select the coincidence tab to enable single counting from both PMTs and display their coincidence counts. Both detectors should be counting at a higher rate than the coincidence events; you can also determine which of the two detectors is limiting the coincidence trigger rate. Proper behavior verifies the threshold settings and the width of the coincidence time window. Record the working parameters and do not adjust the PMT voltage.

Open the LabVIEW program Muon.vi. With appropriate timing settings and threshold parameters determined above, this program records photon events collected by the PMTs. Two measurements can be performed: photon energy distribution and muon decay lifetime.

**Energy distribution:** Select the measurement 'Energy' and open the Coincidence tab. The experiment can be done with a single PMT, but more reliable data is obtained with simultaneous signals from two PMTs to verify the presence of a valid photon in the scintillator. The goal of this measurement is to determine the approximate energy of each photon event by recording its time above threshold, shown as T in the above figure. The gate width can be set with the aid of the oscilloscope. It should be long enough to capture the photon signal; too long will introduce unnecessary noise. Since the width of the triggering photon is of interest, the gate minimum should be set to zero. Only data from one of the PMTs (decay detector) will be recorded.

Start the program and wait 3 seconds for the card to initialize. When the card is ready, press the RUN button. You will be prompted to specify the name and location of a data file where the

collected values of T (in ns) will be written. Since data can be collected for an arbitrarily long time, this file will auto-save at a user-specified interval. Real-time data is displayed on an updating histogram. The distribution should approach an ideal Gaussian depending on the number of data points and histogram bins.

When sufficient data has been collected, stop the program. Repeat the measurement but stop it when the number of data points is about half of the first run. Change the decay detector to the other PMT and do the same pair of measurements (4 total). For the analysis, produce a histogram with a Gaussian fit for all the data sets to determine the mean pulse width and variance; express the latter as a percentage of the mean. How does the analysis depend on the number of histogram bins? Comment on the differences and calculate the experimental uncertainty for each data set.

**Muon decay:** Select the measurement 'Decay' and open the Coincidence tab. In this experiment, the decay detector waits for a second photon that follows the coincidence trigger, which should correspond to a muon decay. The program must be configured to ignore trigger events, which will radically skew the data toward time zero. The gate minimum setting must be set longer than duration of any possible trigger pulse, accounting for fluctuations introduced by the coincidence time window. (Tip: The gate minimum should be longer than the gate width used in the preceding experiment) To observe the expected exponential decay, the gate should remain open for several muon decay lifetimes (order of microseconds). If the gate width is set longer than 5 muon lifetimes, data accumulated at long times will represent the noise background. The background data introduces a constant offset on the statistics that can be subtracted. The desired decay events are statistically rare, so an hour or more may be needed to accumulate a useful data set. When sufficient data is collected, stop the program. The time events are all written to the specified data file. For the analysis, setup an appropriate histogram on a semi-log plot. The slope of the linear fit is the measured muon decay lifetime. Calculate the experimental uncertainty and compare the lifetime to the accepted value.

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7. W.R. Leo, Ch. 12, *NIM Electronics*.
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## APPENDIX 1: Time-to-Amplitude Converters

Bill Miller and Paul Schwoebel

A Time-to-Amplitude Converter (TAC) is a device that accepts a start pulse and waits for a stop pulse. Circuitry inside the TAC determines how much time has elapsed between the two pulses. The TAC produces a voltage pulse with an amplitude that is proportional to the elapsed time.

To use the TAC:

1. Check if there are any special power requirements like  $\pm 6$  V. This can usually be found on the front panel. Some units have a rear panel switch that allows for either  $\pm 12$  V or  $\pm 6$  V. Make sure that your NIM bin has correct voltages available.
- 2) Check to see what logic family the unit uses, NIM logic (a "V" looking character) or TTL (a representation of a positive going pulse). Some units can be switched between the logics.
- 3) Set up the TAC for the proper time scale. If you set it up for a 1  $\mu$ s scale and give it a signal with 2  $\mu$ s between start and stop you will not get an output from the TAC. Similarly, If you select 1  $\mu$ s and deliver only 1 ns the TAC will provide no output.
- 4) There can be a number of extra functions on the front panel. For *COINC* and *ANTICOINC* select *ANTICOINC*. *GATE* should be *OPEN*. The *SCA* is not important for this experiment. Leave the *ULD* at 10 and the *LLD* at 0. Buttons or switches associated with the *SCA* should be set to *OFF* or *OUT*. Anything that says *DELAY* is not important. This adjusts the time between the accepted *STOP* signal and the TAC output pulse. For slow count rates, 10  $\mu$ s is nothing to worry about.

**APPENDIX 2: Gamma-Ray Spectroscopy**  
**EG&G ORTEC**

**Experiments in Nuclear Science**  
**AN34 Laboratory Manual Third Edition, Revised**

Introduction to Theory and Basic Applications  
Alpha, Beta, Gamma, X-Ray, and Neutron  
Detectors and Associated Electronics

Published September 1987.

[Next Page](#)

# Gamma-Ray Spectroscopy Using NaI(Tl)

**EQUIPMENT NEEDED FROM EG&G ORTEC FOR  
EXPERIMENTS 3.1 THROUGH 3.7, 3.9, and 3.10**

- Bin and Power Supply
- 905-3 NaI(Tl) Crystal and Phototube Assembly
- 266 Photomultiplier Tube Base
- 556 High Voltage Power Supply
- 113 Scintillation Preamplifier
- 575A Amplifier
- <sup>137</sup>Cs gamma source, 5  $\mu$ Ci  $\pm$ 5%
- SK-1G Source Kit (see Appendix)
- Absorber Kit Model 3-Z2
- Absorber Kit PbAl-23
- M-Nal-3 Stand for Sodium Iodide Detector

- ACE-2K MCA System including suitable IBM PC (other EG&G ORTEC MCAs may be used)
- Oscilloscope

**ADDITIONAL EQUIPMENT NEEDED FROM EG&G ORTEC  
FOR EXPERIMENT 3.8**

- 427A Delay Amplifier
- 551 Timing Single-Channel Analyzer
- 426 Linear Gate
- 875 Counter

## Purpose

The purpose of this experiment is to acquaint the student with some of the basic techniques used for measuring gamma rays. It is based on the use of a sodium iodide (NaI) detector that is thallium (Tl) activated.

## Gamma Emission

Most isotopes that are used for gamma measurements also have betas in their decay schemes. The typical decay scheme for the isotope will include a beta decay to a particular level followed by gamma emission to the ground state of the final isotope. The beta particles will usually be absorbed in the surrounding material and not enter the scintillator at all. This absorption is normally assured with aluminum absorbers (ref. 10). For this experiment the betas offer no real problem, and so absorbers are not specified. There will be some beta absorption by the light shield over the phototube. The gammas, however, are quite penetrating and will pass easily through the aluminum light shield.

Generally there are two unknowns that we would like to investigate about a gamma source. One is the energies of the gammas from the source; the other is the number of gammas

that leave the source per unit of time. In this experiment the student will become familiar with some of the basic NaI(Tl) measurements associated with gamma-emitting unknowns.

A total time of  $\sim$ 6 h is required to complete all the parts of Experiment 3 (3.1 through 3.10). The complete series can be done in two 3-h lab periods, since each is written to be fairly independent of the others.

## EXPERIMENT 3.1

### Energy Calibration

#### Setup of Equipment

Set up the electronics in the arrangement shown in Fig. 3.1. There are two parameters that ultimately determine the overall gain of the system: the high voltage that is furnished to the phototube and the gain of the linear amplifier. The gain of the photomultiplier tube is quite dependent upon its high voltage. A rule of thumb for most phototubes is that a 10% change of the high voltage will change the gain by a factor of 2. The high-voltage value depends on the phototube being

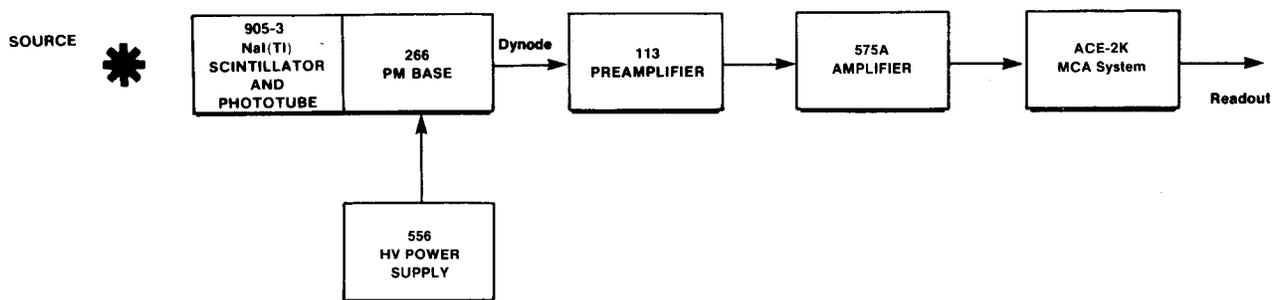


Fig. 3.1. Electronic Block Diagram for Gamma-Ray Spectroscopy System with NaI(Tl) Detector.

used; consult your instruction manual for the phototube and select a value in the middle of its normal operating range. (The instructor may wish to recommend a value.)

Set the indicated modules as follows:

556 High Voltage: See phototube instructions and set the level at about the middle of the acceptable operating range (normally about +1000 V).

113 Scintillation Preamplifier: Set the Input Capacity switch at 200 pF. The output pulses will be positive.

575A Amplifier: Positive input and Bipolar output. Shaping time set to 0.5  $\mu$ sec. The gain will be adjusted during the experiment.

Multichannel Analyzer: PHA Analysis mode; 1000 channels are adequate for this experiment.

**Procedure**

1. Place the  $^{137}\text{Cs}$  source from SK-1G ( $E_\gamma = 0.662$  MeV)  $\sim 2$  cm in front of the NaI(Tl) crystal.
2. Adjust the coarse and fine gain controls of the linear amplifier so that the 0.662-MeV photopeak for  $^{137}\text{Cs}$  falls at approximately channel 280. For the illustrations shown in Figs. 3.2 and 3.3, the gain of the system has been set so that 1 MeV falls at about channel 420 to 425. Since the system is linear, 2 MeV would therefore fall at approximately channel 840 to 850.

3. Accumulate the  $^{137}\text{Cs}$  spectrum for a time period long enough to determine the peak position. Figure 3.2 shows a typical  $^{137}\text{Cs}$  spectrum that has been plotted. Although these spectra are usually plotted on semilog graph paper, the figures shown in this experiment are plotted on linear paper to point out some of the features of the spectra.

4. After the  $^{137}\text{Cs}$  spectrum has been read out of the MCA, erase it and replace the  $^{137}\text{Cs}$  source with a  $^{60}\text{Co}$  source from SK-1G.

5. Accumulate the spectrum for a period of time long enough for the spectrum to be similar to that in Fig. 3.3.

6. Read out the MCA.

**EXERCISES**

- a. Plot both the  $^{137}\text{Cs}$  and  $^{60}\text{Co}$  spectra and fill in items 1, 2, and 3 in Table 3.1.
- b. From items 1, 2, and 3 in Table 3.1 make a plot of energy of the photopeaks vs channel number. Figure 3.4 shows this calibration for the data taken from Figs. 3.2 and 3.3. If other calibration sources are available, additional data points can be added to Fig. 3.4. The other entries in Table 3.1 will be filled out in Experiment 3.3.
- c. Use the energy calibration feature of the MCA and compare the results with those found in Exercise b.

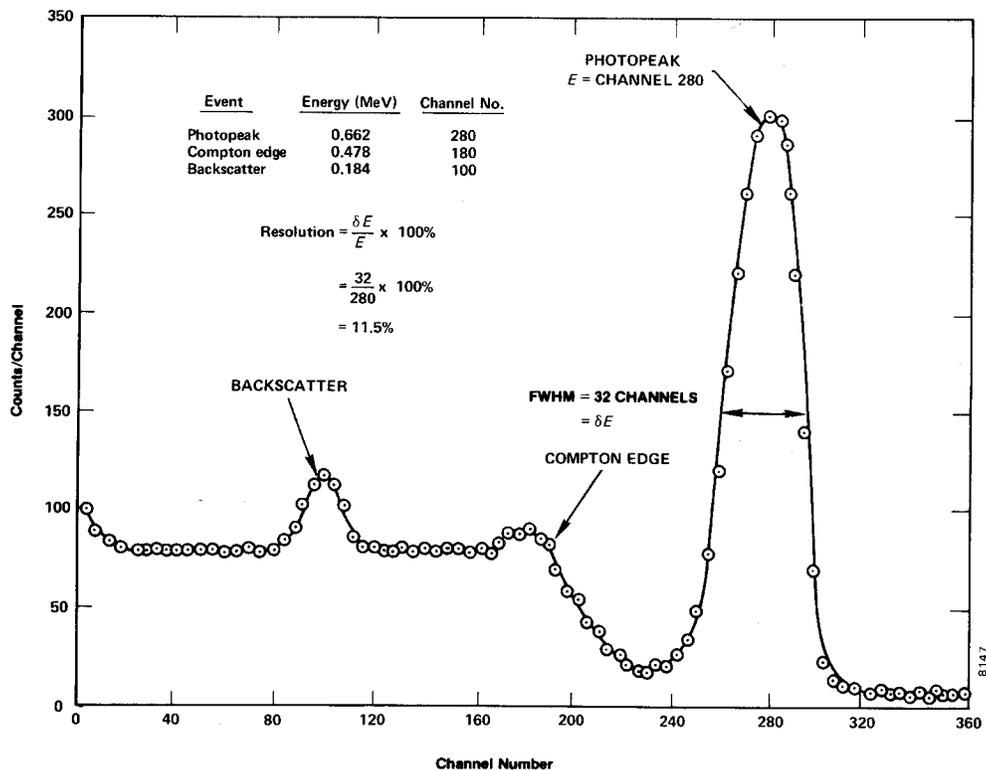


Fig. 3.2. NaI(Tl) Spectrum for  $^{137}\text{Cs}$ .

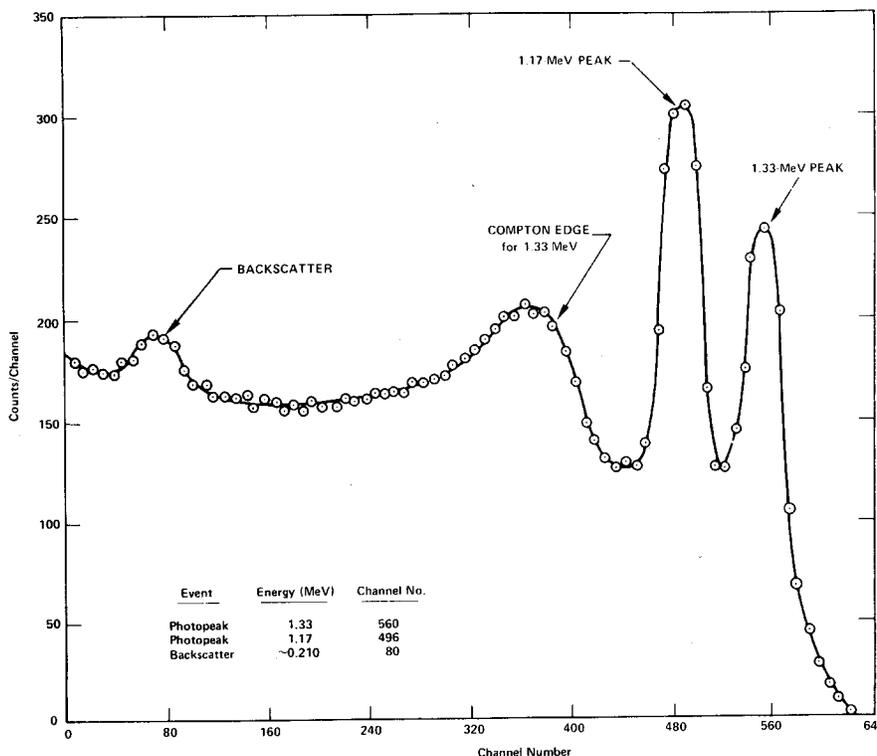


Fig. 3.3. NaI(Tl) Spectrum for <sup>60</sup>Co.

Table 3.1

	Event	Energy (MeV)	Channel Number
1.	0.662-MeV photopeak	0.662	
2.	1.17-MeV photopeak	1.17	
3.	1.33-MeV photopeak	1.33	
4.	Compton edge <sup>137</sup> Cs		
5.	Backscatter <sup>137</sup> Cs		
6.	Backscatter <sup>60</sup> Co		

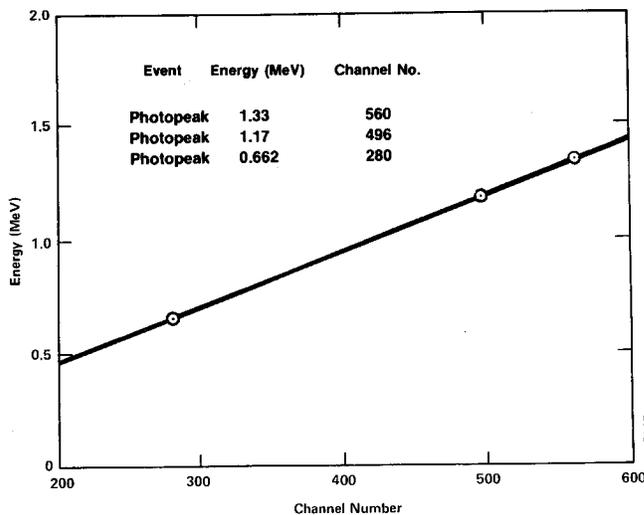


Fig. 3.4. Energy Calibration Curve for NaI(Tl) Detector.

**EXPERIMENT 3.2**

**Energy Analysis of an Unknown Gamma Source**

**Purpose**

The purpose here is to use the calibrated system of Experiment 3.1 to measure the photopeak energies of an unknown gamma emitter and to identify the unknown isotope.

**Procedure**

1. Erase the <sup>60</sup>Co spectrum from the MCA, but do not change any of the gain calibration settings of the system.

2. Obtain an unknown gamma source from the instructor. Accumulate a spectrum for the unknown source for a period of time long enough to clearly identify the photopeak(s) of the source. From the calibration curve, determine the energy for each photopeak.

**EXERCISE**

Use refs. 7 and 8 to identify the unknown isotope.

EXPERIMENT 3.3

## Spectrum Analysis of <sup>60</sup>Co and <sup>137</sup>Cs

### Purpose

The purpose of this experiment is to explain some of the features, other than the photopeaks, that are usually present in a pulse-height spectrum. These are the Compton edge and the backscatter peak.

The Compton interaction is a pure kinematic collision between a gamma photon and what might be termed a free electron in the NaI(Tl) crystal. By this process the incident gamma gives up only part of its energy to the electron. The amount given to the recoil electron (and the intensity of the light flash) depends on whether the collision is head-on or glancing. For a head-on collision the gamma imparts the maximum allowable energy for the Compton interaction. The energy of the scattered gamma can be determined by solving the energy and momentum equations for this billiard ball collision. The solution for these equations in terms of the scattered gamma can be written approximately as

$$E_{\gamma'} \cong \frac{E_{\gamma}}{1 + 2E_{\gamma}(1 - \cos\theta)} \quad (1)$$

where

$E_{\gamma'}$  = energy of the scattered gamma in MeV,

$\theta$  = the scattering angle for  $\gamma'$ ,

$E_{\gamma}$  = the incident gamma-ray energy in MeV.

If  $\theta = 180^\circ$  due to a head-on collision in which  $\gamma'$  is scattered directly back, Eq. (1) becomes

$$E_{\gamma'} \cong \frac{E_{\gamma}}{1 + 4E_{\gamma}} \quad (2)$$

As an example, we will calculate  $E_{\gamma'}$  for an incident gamma energy of 1 MeV:

$$E_{\gamma'} = \frac{1 \text{ MeV}}{1 + 4} = 0.20 \text{ MeV} \quad (3)$$

The energy of the recoil electron,  $E_e$ , for this collision would be 0.80 MeV. This is true since

$$E_e = E_{\gamma} - E_{\gamma'} \quad (4)$$

Then the position of the Compton edge, which is the maximum energy that can be imparted to an electron by the Compton interaction, can be calculated by Eq. (4).

---

### EXERCISES

---

a. Calculate the energy of the Compton edge for the 0.662-MeV gammas from <sup>137</sup>Cs. Enter this value in Table 3.1. From your plot and calibration curve, does this calculation agree with your measured value?

b. Backscatter occurs when gammas make Compton inter-

actions in the material that surrounds the detector. Figure 3.5 was taken from ref. 10 and is a good illustration of the various events that can take place in a typical source-NaI(Tl) detector-lead shield arrangement. Backscattered gammas from these interactions ( $E_{\gamma'}$ ) make photoelectric interactions in the NaI(Tl) when they enter the crystal. The energy of the backscattered peak can be found by solving Eq. (2).

Solve Eq. (2) for the background gammas from <sup>137</sup>Cs and for the 1.33-MeV gammas from <sup>60</sup>Co. Fill in the rest of Table 3.1. How do your measured energies compare with the theoretical energies from Eq. (2)? If the backscatter peak is not very pronounced in your spectrum, it can be improved by accumulating a spectrum with a sheet of lead absorber placed slightly to the left of the source in Fig. 3.1.

EXPERIMENT 3.4

## Energy Resolution

### Purpose

The resolution of a spectrometer is a measure of its ability to resolve two peaks that are fairly close together in energy. Figure 3.2 shows the gamma spectrum that was plotted for the <sup>137</sup>Cs source. The resolution of the photopeak is found by solving the following equation:

$$R = \frac{\delta E}{E} \times 100, \quad (5)$$

where

R = the resolution in percent,

$\delta E$  = the full width of the peak at half of the maximum count level (FWHM) measured in number of channels,

E = the channel number at the centroid of the photopeak.

In Fig. 3.2 the photopeak is in channel 280 and its FWHM = 32 channels. From Eq. (5) the resolution is calculated to be 11.5%.

---

### EXERCISE

---

Calculate the resolution of the system from your <sup>137</sup>Cs spectrum. Record this value for later reference.

---

EXPERIMENT 3.5

## Activity of a Gamma Emitter (Relative Method)

### Purpose

In Experiments 3.1 and 3.3, procedures were given for determining the energy of an unknown gamma source. Another

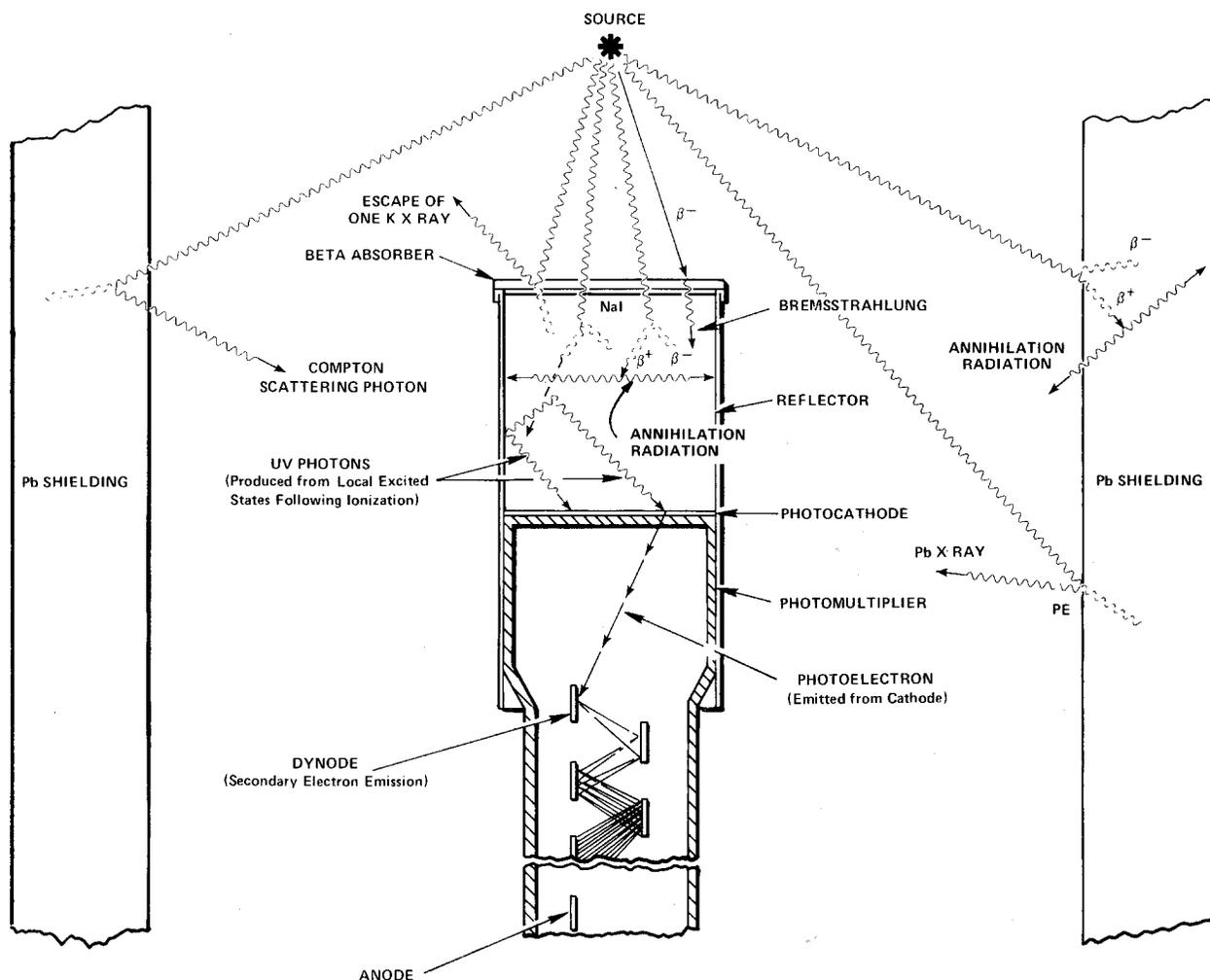


Fig. 3.5. Various Events in the Vicinity of a Typical Source-Crystal Detector-Shield Configuration.

unknown associated with the gamma source is the activity of the source, which is usually measured in curies (Ci);  $1 \text{ Ci} = 3.7 \times 10^{10}$  disintegrations/s. Most of the sources that are used in nuclear laboratory experiments have activities of the order of microcuries ( $\mu\text{Ci}$ ). The purpose of this experiment is to outline one procedure by which the activity of a source can be determined, called the relative method.

In using the relative method, it is assumed that the unknown source has already been identified from its gamma energies. For this example, assume that the source has been found to be  $^{137}\text{Cs}$ . Then all that is necessary is to compare the activity of the unknown source to the activity of a standard  $^{137}\text{Cs}$  source that will be supplied by the laboratory instructor. For convenience, call the standard source S1 and the unknown source U1.

### Procedure

1. Place the S1 source about 4 cm from the face of the detector (or closer if necessary to get reasonable statistics)

and accumulate a spectrum for a period of live time, selectable on the analyzer, long enough to produce a spectrum similar to Fig. 3.2.

2. Use the cursor to determine the sum under the photopeak. In the example shown in Fig. 3.2, this would correspond to adding up all counts in channels 240 through 320. Define this sum to be  $\Sigma_{S1}$ .

3. Erase the MCA spectrum. Remove source S1 and replace it with source U1, positioned **exactly** the same distance from the crystal as the S1 source was. Accumulate a spectrum for the same period of live time that was used in step 1. Sum the peak as in step 2.

4. Erase the spectrum from the MCA. Remove the U1 source and accumulate background counts for the same period of live time that was used in steps 1 and 3 above.

5. Sum the background counts in the same channels that were used for the photopeaks in steps 2 and 3 above. Call this sum  $\Sigma_b$ .

**EXERCISE**

Solve for the activity of the U1 by using the following ratio:

$$\frac{\text{activity of U1}}{\text{activity of S1}} = \frac{\Sigma_{U1} - \Sigma_b}{\Sigma_{S1} - \Sigma_b} \quad (6)$$

Since the efficiency of the detector is only energy dependent, the standard and unknown sources do not have to be the same isotope. It is only necessary that their gamma energies be approximately the same ( $\pm 10\%$ ) in order to get a fairly good estimate of the absolute gamma activity of the unknown.

**EXPERIMENT 3.6**

**Activity of a Gamma Emitter (Absolute Method)**

**Purpose**

The activity of the standard used in Experiment 3.5 can be determined by the absolute method. The purpose of this experiment is to outline the procedure for this method. Here the source that is to be measured will be called U1.

**Procedure**

1. Place the U1 source 9.3 cm away from the face of the detector.
2. Accumulate a spectrum and note the live time that is used.
3. Use the cursor to determine the sum under the photopeak,  $\Sigma_{U1}$ . Then erase the spectrum, remove the source, and accumulate background for the same live time and calculate  $\Sigma_b$ .
4. Use the following formula to calculate the activity of U1:

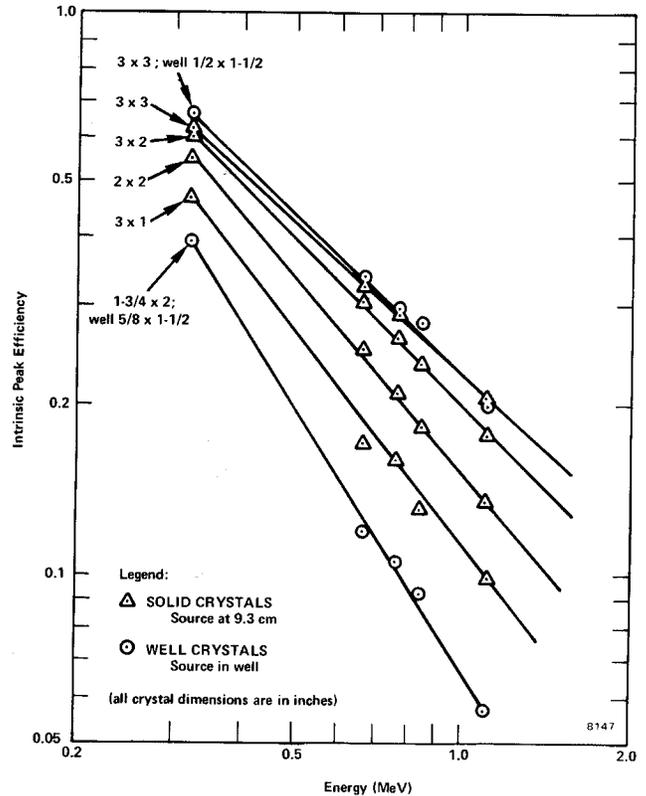
$$\text{activity of U1} = \left( \frac{\Sigma_{U1} - \Sigma_b}{t} \right) \frac{1}{G \epsilon_p f} \quad (7)$$

**Table 3.2. Gamma Decay Fraction, (f), for Some Common Isotopes.**

Isotope	Gamma Energy (MeV)	f
<sup>137</sup> Cs	0.662	0.92
<sup>51</sup> Cr	0.323	0.09
<sup>60</sup> Co	1.17	0.99
<sup>60</sup> Co	1.33	0.99
<sup>22</sup> Na	1.276	0.99
<sup>22</sup> Na	0.511	0.99
<sup>54</sup> Mn	0.842	1.00
<sup>65</sup> Zn	1.14	0.44

where

- t = live time in seconds,
- $\epsilon_p$  = intrinsic peak efficiency for the gamma energy and detector size used (Fig. 3.6 and ref. 10),
- f = the decay fraction of the unknown activity which is the fraction of the total disintegrations in which the measured gamma is emitted (refs. 7 and 8 and Table 3.2),
- G = area of detector ( $\text{cm}^2$ )/ $4\pi s^2$ ,
- s = source-to-detector distance in cm.



**Fig. 3.6. Intrinsic Peak Efficiency of Various NaI(Tl) Crystals vs Gamma Energy.**

**EXPERIMENT 3.7**

**Mass Absorption Coefficient**

**Purpose**

The purpose of the experiment is to measure experimentally the mass absorption coefficient in lead for 662-keV gamma rays.

References 2, 3, and 5 point out that gammas interact in matter primarily by photoelectric, Compton, or pair-production interactions. The total-mass absorption coefficient can be measured easily with a gamma-ray spectrometer. In this experiment we will measure the number of gammas that are removed from the photopeak by photoelectric or Compton

interactions that occur in a lead absorber placed between the source and the phototube.

From Lambert's law (ref. 1) the decrease of intensity of radiation as it passes through an absorber is given by

$$I = I_0 e^{-\mu x}, \quad (8)$$

where

- I = intensity after the absorber,
- I<sub>0</sub> = intensity before the absorber,
- μ = total-mass absorption coefficient in cm<sup>2</sup>/g,
- x = density thickness in g/cm<sup>2</sup>.

The density thickness is the product of the density in g/cm<sup>3</sup> times the thickness in cm.

The half-value layer (HVL) is defined as the density thickness of the absorbing material that will reduce the original intensity by one-half. From Eq. (8):

$$\ln I/I_0 = -\mu x. \quad (9)$$

If I/I<sub>0</sub> = 0.5 and x = HVL,  $\ln 0.5 = -\mu(\text{HVL})$  and hence

$$\text{HVL} = \frac{0.693}{\mu} \quad (10)$$

In this experiment we will measure μ in lead for the 0.662-MeV gammas from <sup>137</sup>Cs. The accepted value is 0.105 cm<sup>2</sup>/g. Values for other materials can be found in ref. 8.

### Procedure

1. Place the <sup>137</sup>Cs source about 5.0 cm from the NaI(Tl) detector and accumulate the spectrum long enough for the sum under the 0.662-MeV peak (Σ<sub>Cs</sub> - Σ<sub>b</sub>) to be at least 6000 counts. Determine (Σ<sub>Cs</sub> - Σ<sub>b</sub>).
2. Erase the MCA and insert a piece of lead from the absorber kit between the source and the detector. Accumulate the spectrum for the same period of live time as in step 1 above. Determine (Σ<sub>Cs</sub> - Σ<sub>b</sub>).
3. Erase the MCA and insert another piece of lead. Determine (Σ<sub>Cs</sub> - Σ<sub>b</sub>). Repeat with additional thicknesses of lead until the count-sum is >1000. Fill in the data in Table 3.3.

Table 3.3. Data for Mass Absorption Coefficient.

Absorber	Absorber Thickness (mg/cm <sup>2</sup> )	Σ <sub>Cs</sub> - Σ <sub>b</sub>
1	0	
2		
3		
4		
5		
6		
7		

### EXERCISES

- a. Using semilog graph paper, plot I vs absorber thickness in mg/cm<sup>2</sup>, where I = (Σ<sub>Cs</sub> - Σ<sub>b</sub>)/live time. Determine the HVL from this curve and calculate μ from Eq. (10). How does your value compare with the accepted value of 0.105 cm<sup>2</sup>/g?
- b. Repeat the above experiment for the aluminum absorbers in the Absorber Kit. The μ for aluminum is 0.074 cm<sup>2</sup>/g.

### EXPERIMENT 3.8

## The Linear Gate in Gamma-Ray Spectroscopy

### Purpose

The purpose of this experiment is to show how a linear gate can be used with an MCA in gamma-ray spectroscopy. The linear gate will limit the analysis of input pulse amplitudes to those that will be included within the photopeak.

The measurement of the mass absorption coefficient in Experiment 3.7 required the accumulation of several complete spectra, although the data of interest were included within only a fraction of the total number of channels that were used. The normal time for completing Experiment 3.7 is approximately 45 min. By using a linear gate, the same information can be obtained in about 1/3 of the time. An equivalent saving of time can also be made in Experiments 3.5 and 3.6 (Source Activity Determinations). Since the procedures are about the same as for Experiment 3.7, the student should repeat these experiments with the linear gate to see how much time will be saved.

See equipment list at beginning of Experiment 3 for additional equipment required for Experiment 3.8.

Connect the system components as shown in Fig. 3.7. Connect the bipolar output of the 575A Amplifier to both the 427A Delay and the 551 Timing Single-Channel Analyzer. Connect the Delay output to the linear Input of the 426 Linear Gate and connect the gate output to the analyzer input. Connect the SCA output to both the 875 Counter input and the Enable input of the Linear Gate.

The Linear Gate is a module that permits linear pulses to be passed only during the time interval that follows each Enable input. In normal operation the adjusted time interval will allow only one linear pulse to be furnished into the MCA.

The Timing Single-Channel Analyzer determines whether each input pulse amplitude is within the window and generates a logic output pulse for each input pulse that satisfies the criteria. By adjusting the lower and upper levels of its window, the 551 then can determine what portion of the spectrum is gated through for analysis in the MCA. This is true since it delivers the enable logic pulse to open the linear gate.

From the standpoint of timing, one would like to have the logic pulse arrive at the enable input of the linear gate just prior to the arrival of the corresponding linear pulse that is to be gated. Since the amplifier provides a bipolar output to the SCA, and since the SCA generates an output at 50% of full amplitude on the trailing edge of the positive lobe, the SCA output will occur at about  $2 \mu\text{s}$  after the onset of the pulse. Thus, if the 427A Delay is set for  $3 \mu\text{s}$  and the 426 Linear Gate width is adjusted to maximum,  $4 \mu\text{s}$ , the gate passes the input pulse for a period from  $1 \mu\text{s}$  before the delayed pulse reaches the 426 until  $3 \mu\text{s}$  of elapsed pulse time. This passes the positive portion of the bipolar pulse, which is all that affects the MCA measurement; the negative portion of the bipolar pulse is not used.

The inclusion of a counter in Fig. 3.7 permits a direct total of the counts to be observed, and the adjustment of the window width will limit these to the peak area. This simplifies the summing of counts for peak area integrations.

Figure 3.8 shows how Fig. 3.2 might look if the window of the SCA were set properly to just span the  $^{137}\text{Cs}$  photopeak. Since the MCA has a live display while it is accumulating, it is quite simple to adjust the window of the SCA properly.

The single-channel principle and the control of the linear gate are examined here with individual modules. Both functions are also included in the MCA, so the separate modules are not required for other experimental applications.

**Module Settings:**

Use the same settings for the high-voltage power supply, preamplifier, and amplifier that were used for Experiment 3.1. Set the 426 Linear Gate for Normal with its Gate Width control fully clockwise for  $4 \mu\text{s}$ . Set the 875 Counter for count and use the Positive input from one of the Pos Out connectors on the 551 Timing SCA; reset the 875 Counter to zero. Set the 551 Timing SCA for Normal operation, the Lower-Level control at 030, the Upper-Level control fully clockwise

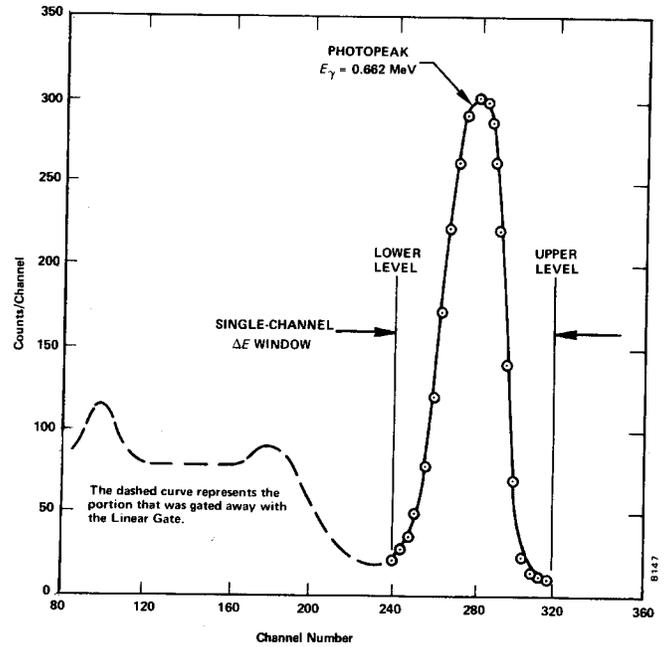


Fig. 3.8.  $^{137}\text{Cs}$  Spectrum with the Linear Gate.

at 1000 divisions, and Delay at minimum for  $0.1 \mu\text{s}$ . Set the 427A Delay Amplifier for a  $3\text{-}\mu\text{s}$  delay.

**Procedure**

1. Place the  $^{137}\text{Cs}$  source from SK-1G about 4 or 5 cm from the crystal face. Accumulate a spectrum in the MCA while adjusting the E and the  $\Delta E$  window on the 551 Timing SCA. Set the window so that it just brackets the photopeak as in Fig. 3.8. You are now ready to make the first measurements.
2. Clear the MCA and reset the counter to zero. Start both at the same time and accumulate for a period of time long enough to obtain about 6000 counts in the counter. Record

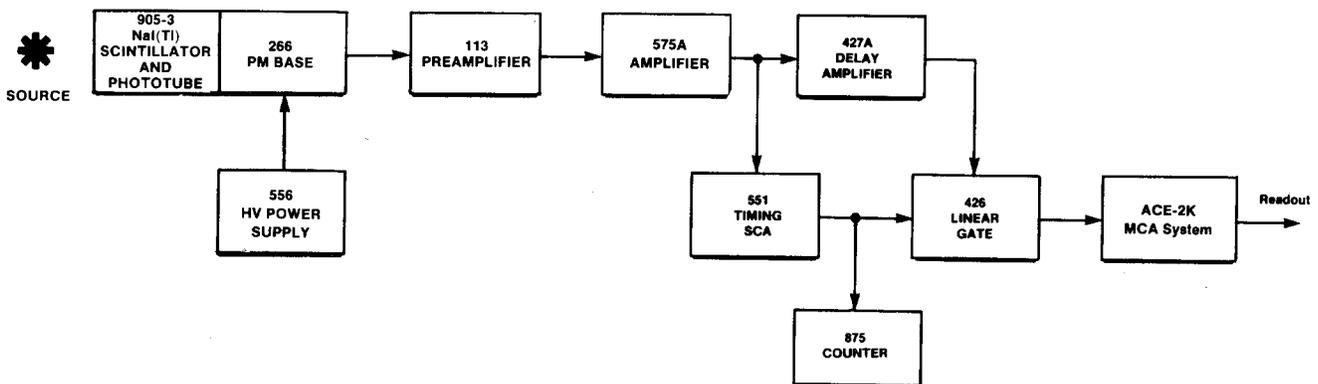


Fig. 3.7. Block Diagram of Electronics for Gamma-Ray Spectrometry System with a Linear Gate.

the total elapsed time for the measurement, the average dead time from the MCA, and the count in the counter. Read out the analyzer and then clear both the MCA and the counter.

3. Place the first lead absorber between the source and the detector as in Experiment 3.7 and accumulate for the same period of time that was used in step 2 above. Record only the counter counts and the total elapsed time. It is not necessary to read out the MCA for each spectrum since the counter is summing the counts under the photopeak. You should observe the MCA for each spectrum to make sure that the proper spectrum is being stored.

4. Repeat step 3 for each added absorber thickness that was used in Experiment 3.7. Make a background run with the source removed, and fill in Table 3.4 as in Experiment 3.7.

Table 3.4

Absorber	Absorber Thickness (mg/cm <sup>2</sup> )	$\Sigma_{cs} - \Sigma_b$
1	0	
2		
3		
4		
5		
6		
7		

5. Calculate the same data as in Experiment 3.7, Exercises a and b.

6. In step 2 the output of the MCA was read. Sum this output spectrum and compare it with the counter sum that was taken from the same run. The counter sum should be slightly larger since it does not suffer from dead-time corrections at these counting rates. The MCA does suffer, because it requires some amount of time to measure and store each pulse and thus does not actually analyze as many pulses as have been furnished to it. The MCA sum should be equal to the counter count times the percent of live time, which is equal to the live time of the MCA divided by the clock time for the spectrum accumulation.

### EXPERIMENT 3.9

## Sum Peak Analysis

Figure 3.3 shows the two pronounced peaks in <sup>60</sup>Co. Figure 3.9 shows the decay scheme of <sup>60</sup>Co.

Most of the time the decay occurs by  $\beta$  emission to the 2.507-MeV excited state of <sup>60</sup>Ni. Subsequent decay to the ground state always occurs by gamma emission to the 1.3325-MeV level (a 1.174-MeV gamma) followed almost simultaneously by the 1.3325-MeV gamma to the ground state. In Experi-

ment 19 we will show that these two events are in coincidence and have an angular correlation that deviates from an isotropic distribution by only 16%. For the purposes of this experiment we can assume that each of these gammas are isotropically distributed. In other words, if  $\gamma_1$  goes in a particular direction,  $\gamma_2$  can go in any of the  $4\pi$  steradians that it wishes. There is a certain probability that it will go in the same direction as  $\gamma_1$ . If this occurs within the resolving time of the detector,  $\gamma_1$  and  $\gamma_2$  will be summed and hence a sum peak will show up in the spectrum. From the definitions in Experiment 3.6, the number of counts,  $\Sigma_1$ , under the  $\gamma_1$  peak is given by:

$$\Sigma_1 = \epsilon_1 G f_1 t A, \tag{11}$$

where A is the activity of the sample and t is the time. In a similar calculation, the sum  $\Sigma_2$  for  $\gamma_2$  is given by:

$$\Sigma_2 = \epsilon_1 G f_2 t A. \tag{12}$$

From Eqs. (11) and (12) the number of counts in the sum peak,  $\Sigma_s$ , is given by:

$$\Sigma_s = \epsilon_1 \epsilon_2 f_1 f_2 G^2 A t [W(0^\circ)], \tag{13}$$

where  $W(0^\circ)$  is a term that accounts for the angular correlation function. For the case of <sup>60</sup>Co, Eq. (13) is quite simple.  $\Sigma_s$  becomes:

$$(\Sigma_s)_{60\text{Co}} \cong \epsilon_1 \epsilon_2 G^2 A t, \tag{14}$$

since  $W(0^\circ) \cong 1.0$ .

In this experiment we will show that the sum peak for <sup>60</sup>Co has an energy of 2.507 MeV and that its sum is given by Eq. (14).

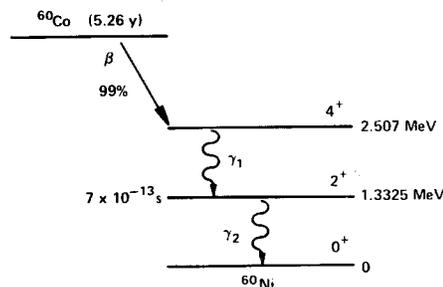


Fig. 3.9. The Decay Scheme of <sup>60</sup>Co.

### Procedure

1. Set up the electronics as shown in Fig. 3.1.
2. Use the gammas from the source kit to calibrate the MCA so that full scale is  $\sim 3.0$  MeV. For 1024 channels this would put the <sup>137</sup>Cs (0.662 MeV) peak at approximately channel 225.
3. Construct a calibration curve as in Experiment 3.1.
4. Place the <sup>60</sup>Co source from the source kit at exactly 9.3 cm from the face of the detector. Count for a period of time long enough so that the area under the sum peak is  $\sim 1000$  counts. This procedure was outlined in Experiment 3.6.

EXERCISES

- a. Verify that the energy of the sum peak is 2.507 MeV. Subtract the background from the sum peak and verify its sum from Eq. (14).
- b. Repeat this sum peak analysis for the <sup>22</sup>Na source. Figure 3.10 shows the decay scheme for <sup>22</sup>Na and a typical spectrum with the sum peak.

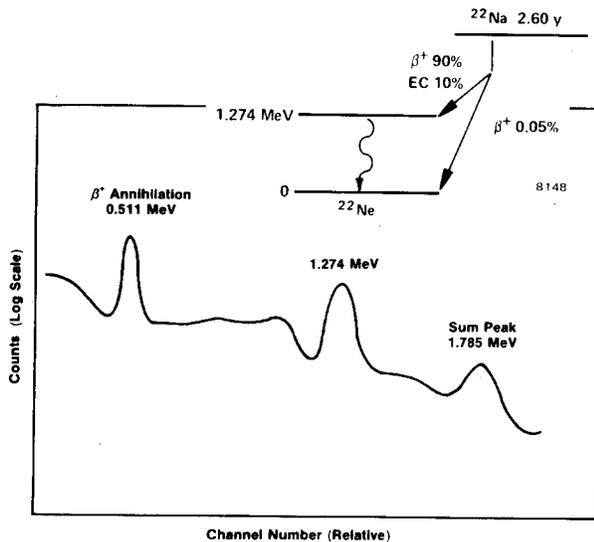


Fig. 3.10. Sum Peak for the <sup>22</sup>Na Source from Source Kit SK-1G.

EXPERIMENT 3.10

Photoelectric Absorption

Purpose

The purpose of this experiment is to study the photoelectric absorption of photons and verify the strong dependence of this process on the atomic number of the absorbing material.

When a gamma of energy <150 keV interacts with matter, the interaction has a high probability of being photoelectric. In the photoelectric interaction, the photon interacts with one of the tightly bound electrons in the material. The electron, in general, is knocked out of the atom with an energy given by:

$$E_e = hf - E_b,$$

where f is the frequency of the photon and E<sub>b</sub> is the binding energy of the electron that is involved in the interaction. The probability of photoelectric interaction is dependent on the atomic number of the absorbing material and the energy of the gamma or x-ray photon. Although it is difficult to write out an exact analytic expression for this probability, it can be shown that for low energy photons

$$\mu = \frac{K \cdot Z^n}{E_\gamma^3}, \tag{15}$$

where K is a constant, Z is the atomic number, and n is usually between 4 and 5.

Procedure

The set up for this experiment is the same as for Experiment 3.7.

1. Place the <sup>57</sup>Co source ~3.8 cm from the NaI detector. Accumulate for a time period long enough to get reasonable statistics in the 122-keV line. As in Experiment 3.7, Σ - Σ<sub>b</sub> should be at least 6000 counts.
2. Clear the MCA and place the thinnest aluminum absorber between the source and the detector. Count for the same period of time as in step 1. Repeat for the other two aluminum absorbers.
3. Repeat steps 1 and 2 for the other thin absorbers, Fe, Cu, Mo, Sn, Ta, and Pb, in the Model 3-Z2 source kit. Note: The counting time might have to be increased as the atomic number of the absorber is increased.

EXERCISES

- a. For the three measurements made with the thin aluminum foils, calculate and average μ, Eq. (9). Repeat for the other absorbers.
- b. Make a plot of μ vs Z<sup>4.5</sup>/E<sub>γ</sub><sup>3</sup> from your experimental data. How do your results compare to the theory?

References

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## **APPENDIX 3: MANUALS**

# ***SPECTECH***

**UCS 30**

Universal Computer  
Spectrometer (USB)

## **Quick Start Guide**

April 2008

### **IMPORTANT NOTE**

Software for this spectrometer should be installed before it is connected and powered on. If you have already connected the **UCS 30** to your computer, do not power on until software installation is complete.

***Spectrum Techniques, LLC.***

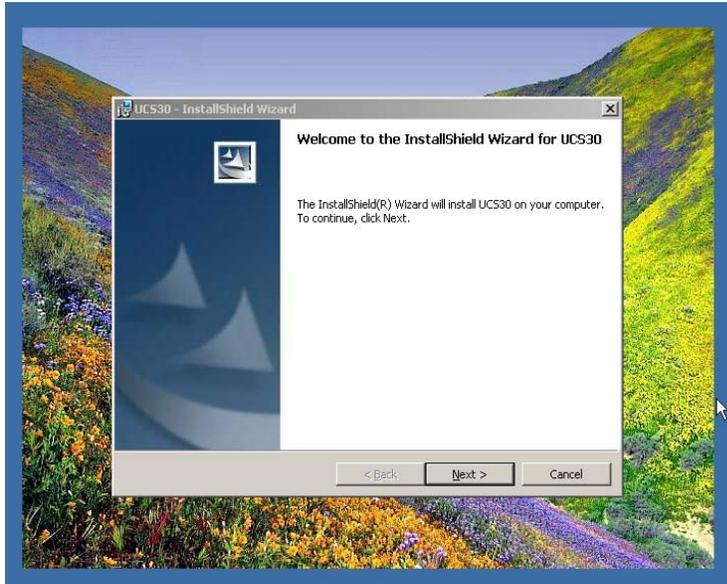
Oak Ridge, Tennessee USA.

## INTRODUCTION

The purpose of this guide is to provide you with assistance to quickly install, setup, and begin using your **UCS 30** Universal Computer Spectrometer (USB).

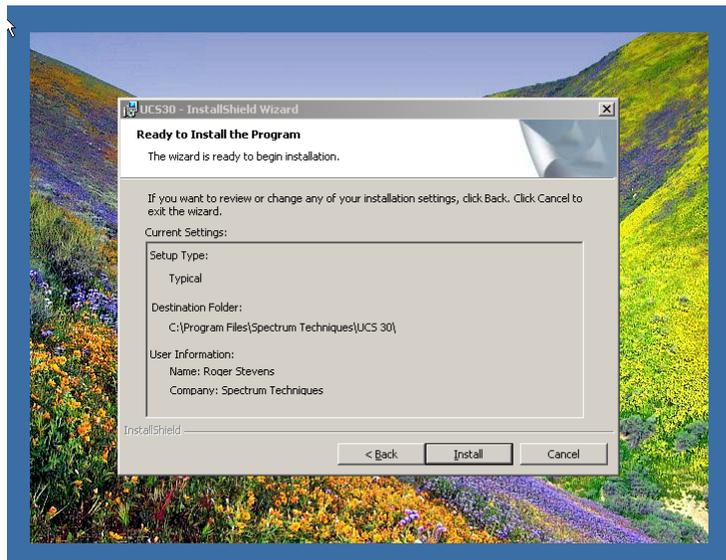
## INSTALL SOFTWARE

Install the software CD shipped with your **UCS 30** system into your CD ROM drive. The auto-start feature will open the InstallShield Wizard. Click **Next** to continue.



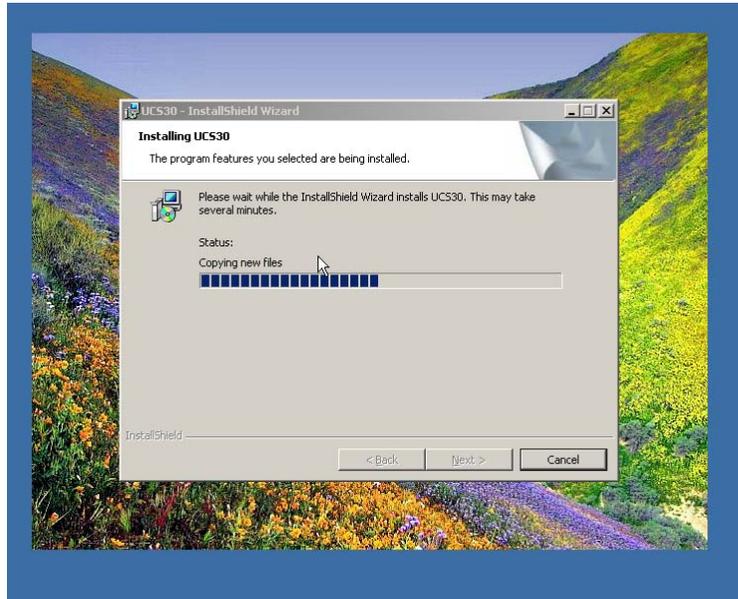
Verify your user information and the default destination folder **C:\Program Files\Spectrum Techniques\UCS30**.

You might want to note this Program installation path in case you want to store spectra in this location.



Click **I**nstall to begin program installation if you are satisfied with your entries.

The installation will begin. You can monitor the install progress by watching the status bar. The install should be reasonably quick and will conclude by displaying the **InstallShield Wizard Completed** screen. Click **F**inish to exit the install wizard.



Note the **UCS 30** icon that has been installed on your desktop.

Using your Windows Explorer, examine the contents of **C:\Program Files\Spectrum Techniques\UCS30\**. This file should contain a **Drivers** folder, an **Examples** folder, and several **UCS 30** files including the **UCS 30 Manual** in Adobe PDF format. You may want to create a shortcut to the manual and place it on your desktop for quick reference.

Remove the installation CD from the CD ROM drive and store it in a safe place.

## **SYSTEM SETUP**

Connect your detector to the **UCS 30**. Connect the detector high voltage cable to the **MHV** connector on the **UCS 30** labeled **POS HIGH VOLTAGE**.

Connect the **BNC** signal cable from the detector to the **BNC** connector on the **UCS 30** labeled **INPUT**.

NOTE: If you are using a detector with a preamplifier included, connect to the **INPUT BNC** connector and set the **UCS 30 MODE** to **PHA (Amp In)**.

If you are using a detector with a preamplifier AND external amplifier, connect the detector signal cable to the **INPUT BNC** connector on the **UCS 30** and set the **MODE** to **PHA (Direct In)**.

Turn on the power to the **UCS 30**.

Your PC should detect the presence of a new hardware device and may automatically install the required software. If the software does not load automatically, follow the system prompts. Remember, the location of the software is **C:\Program Files\Spectrum Techniques\UCS30\**.

After you specify location of your software, you may see the following screen, or similar:



Select **Continue Anyway** and finish the installation.

Start the **UCS 30** program by double-clicking on the **UCS 30** icon on your desktop.

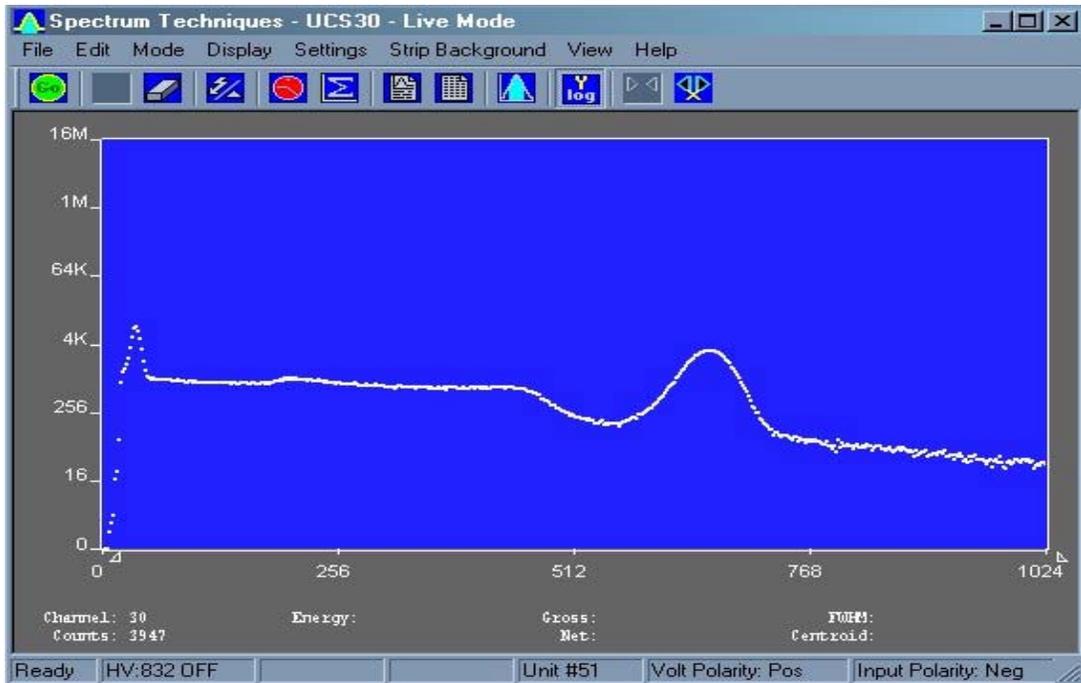
Place a Cs-137 calibration source on your detector.

Next, open the **Settings** pull-down menu. Click on **Energy Calibrate**, then select **Auto Calibrate**. The system will now auto calibrate. This process will take several minutes. Once completed, the message box will display the current settings for high voltage, coarse and fine gain. The screen is now energy calibrated from 0 to 1024 KeV.

Erase spectrum using the **eraser** icon.

Click the **Go** button and take a spectrum until you obtain a well defined peak at the 662 keV line of Cesium. **Stop** the acquisition.

Set the ROI by clicking on **Settings, ROIs**, then **Set ROI**. Place the cursor over the lower channel you wish to start the ROI with, hold down the left mouse key and drag the cursor to the desired upper channel for the ROI. Release the mouse button and the ROI will be set and highlighted. When the cursor is placed anywhere in the ROI, the total counts in the ROI will be displayed.



Now set a preset count. You can choose **Time**, then **Real Time** or **Live Time**, or **Integral Counts**. Let's use **Integral Counts** since we have set a Region of Interest (ROI). Select **Settings, Presets**, then **Integral Counts**. In the box, enter a number for the desired level of counts in the ROI that will stop data acquisition. (Note: You must first have your cursor set in your ROI.)

Click on **File** and **Save Setup**, enter a file name and save. You can use this count protocol whenever you wish by selecting **File, Load Setup** and selecting this file.

### **USING YOUR SYSTEM**

This guide is intended to help you setup and begin using your **UCS 30** as quickly and easily as possible. The more you use the system, the more you will become familiar with its operation.

More detail on operation is provided in the **UCS 30** user's manual.

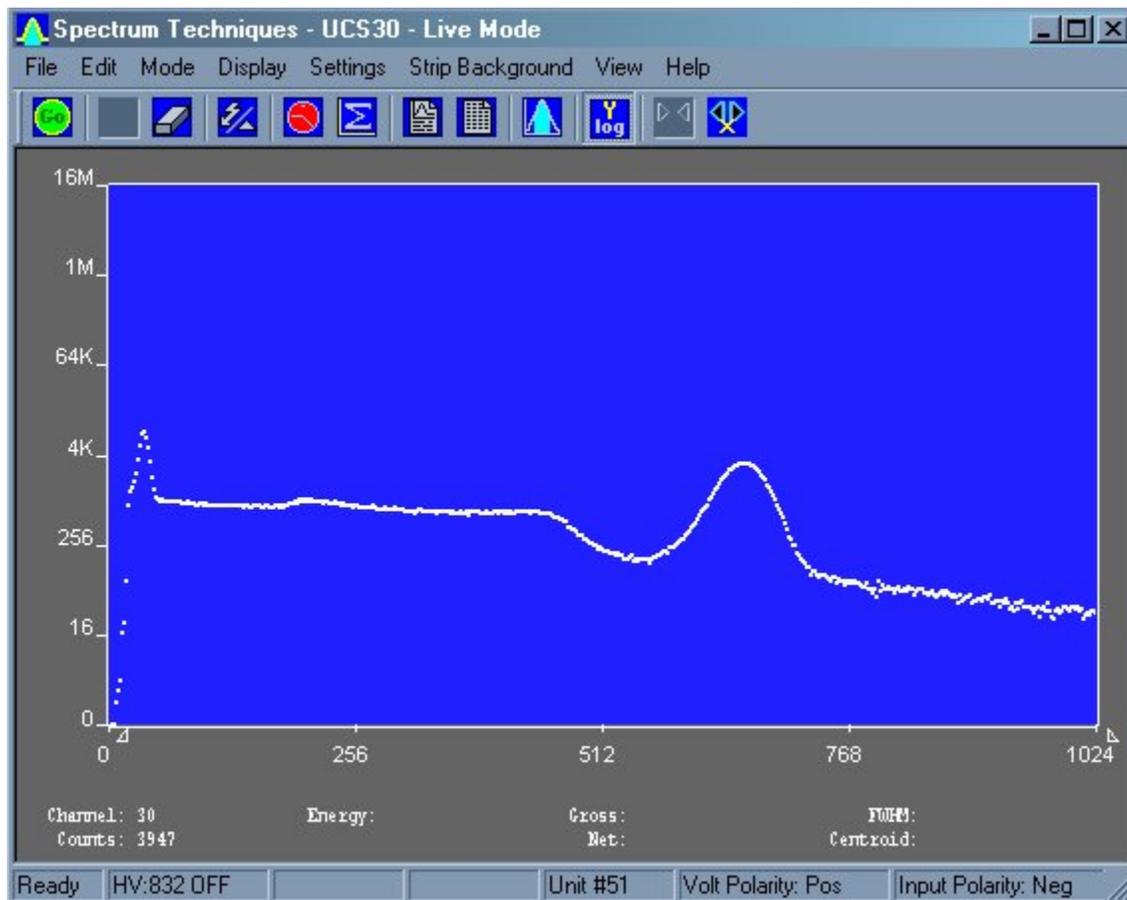
Contact us if you still have questions, comments or problems pertaining to your system or its operation.

Spectrum Techniques  
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<http://www.spectrumtechniques.com>

# *Spectrum Techniques*

## UCS-30

### Universal Computer Spectrometer



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# Introduction

## Hardware

The Universal Computer Spectrometer offers a unique solution for nuclear spectrometry using the PC platform. A 4K ADC (optional) combined with 8K of data memory and multi-channel scaling is ideally suited to scintillation spectroscopy and time related studies such as half-life decay.

Constructed in a sturdy, fully-shielded bench top enclosure with Universal Serial Bus (USB) computer interface, the multi-channel analyzer contains many advanced features including computer controlled amplifier and high voltage for PM tubes, upper- and lower-level discriminators, on-instrument data memory, and a comprehensive software package for use under Windows 2000 or higher.

The UCS-30 requires only an available USB port and is designed to work seamlessly with USB-equipped PCs. For stability and low noise operation, the unit is AC-line powered with an auto-sensing power supply for 100-250 VAC operation. An on-board microprocessor acts as the master controller and data storage device, as well as the communication link directly to the USB interface.

The integrated amplifier and high voltage are fully compatible with most standard scintillation detectors, eliminating the need for special tube bases and external modules. For ease of setup and calibration, coarse gain, fine gain, high voltage, and lower- and upper-level discriminator settings are controlled directly from the desktop computer. For operation with other types of detector systems such as alpha spectrometers or single photon counting, the scintillation preamp and amplifier can be bypassed (by computer control while in the “Mode” menu) which allows direct access to the ADC.

A 4096 channel ADC with de-randomizing buffer offers excellent data throughput at high counting rates with minimal dead-time losses. Conversion gain may be changed from 4096 to either 2048, 1024, 512, or 256 channels via the software. Data from the ADC is stored directly in on-board memory for autonomy and high-speed operation, freeing the host computer for other tasks.

## Software

The UCS-30 produces a high-resolution, real-time live color display of spectral data with standard PC graphics running under Windows<sup>®</sup> (2000 and above). Operation is intuitive using pull-down menus and function buttons for the most commonly used commands and display options. The software offers full control of all features including preset live/real time and regions-of-interest, together with centroid, gross and net area calculations.

Control of the hardware amplifier, high voltage, ADC and input discriminators is also through function buttons for straightforward calibration and operation. To simplify identification of

peaks, the cursor may be calibrated to read directly in energy units, using either a 2-point linear, or 3-point quadratic relationship calibration to allow for detector non-linearity.

Spectral files may be transferred to disk for long-term storage as binary files or transferred through the clipboard in ASCII format for exporting to other programs. Stored files may be used to collect background data over a long counting period that can be subtracted on a time proportional basis from the spectral data.

To aid in the identification of nuclides, the UCS-30 contains a unique peak-labeling feature named ISOMATCH. Providing the unit is accurately energy calibrated, the user may select a nuclide from the library and the corresponding characteristic emission lines are superimposed on the spectrum along with isotope and energy information. Using this feature, users may quickly check a spectrum and visually identify the emission components for each nuclide present. The ISOMATCH libraries may be created or customized using a text editor.

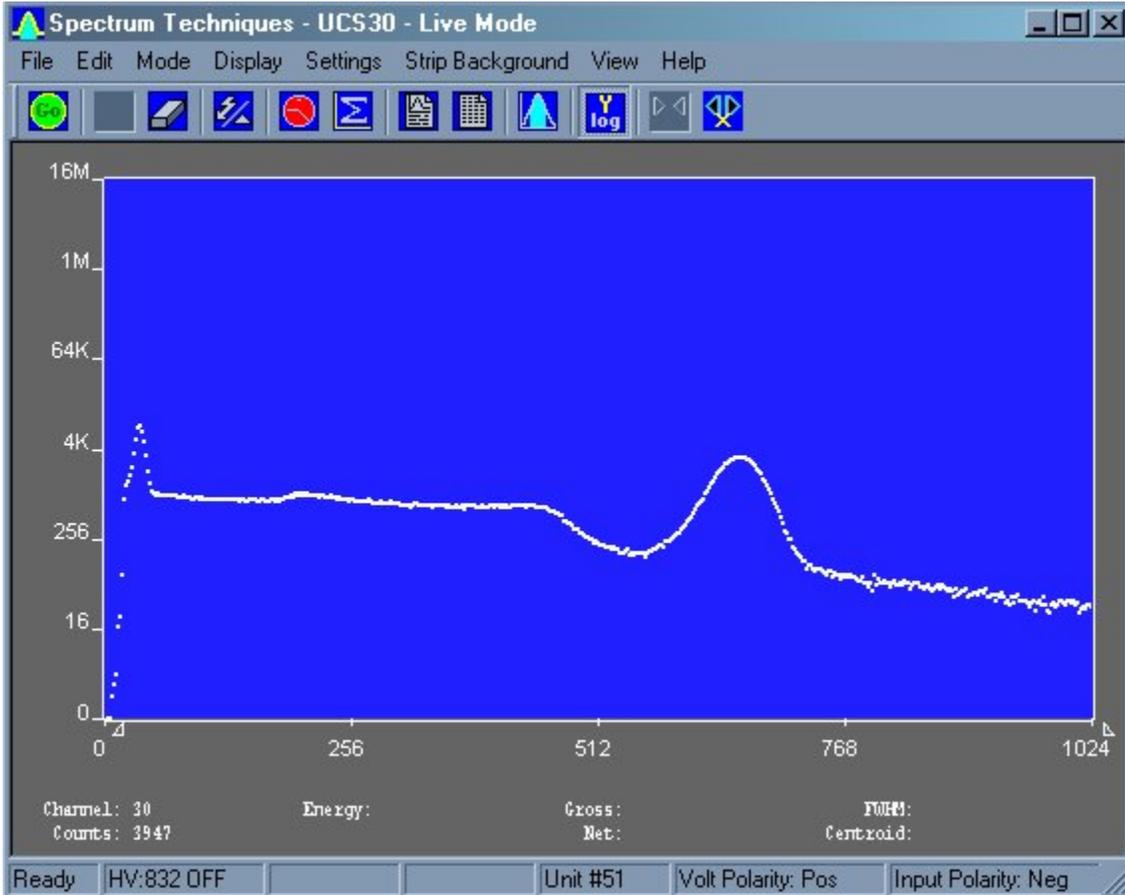
When operating in multi-channel scaling mode, the system may be calibrated in time units for direct readout from the cursor.

Both linear- and logarithmic-vertical display ranges are included, which can be useful when performing decay studies

**Spectrum files can be transferred from the ICS 10 DOS program and the ICSW 16 Windows program to the UCS-30 Windows version format.**

Most functions may be accessed by more than one method. All the functions can be accessed from the Pull Down Menues, some from the Tool Bar Buttons, or by the mouse. If the function has a Tool Bar Button, its symbol will be shown on the left-hand side of the description.

## Screen View



## Installation

### System Requirements

The UCS-30 instrument uses a Universal Serial Bus (USB) to communicate with a PC. The PC must have USB compatible drivers, which are available standard on Windows 2000 and later releases. The performance of the USB on older systems may affect the perceived performance of the software; so we recommend that you use a Pentium III or greater class of microprocessor running at 550 MHz or greater to achieve desirable performance.

### Installing Software

Insert the included CD in your CD-ROM drive. The install program will automatically run. Follow the instructions to select the options you want to install.

The default installation directory is C:\Program Files\Spectrum Techniques\UCS 30

Example files:

**Spectrum (\*.spu) files:**

Normal.spu – contains an uncalibrated spectrum of CS-137.  
Calibrated.spu – contains a calibrated spectrum of CS-137.

**Setup (\*.sup) files:**

Normal.sup – has settings used in Normal.spu.  
Calibrated.sup – has settings used in Calibrated.spu.

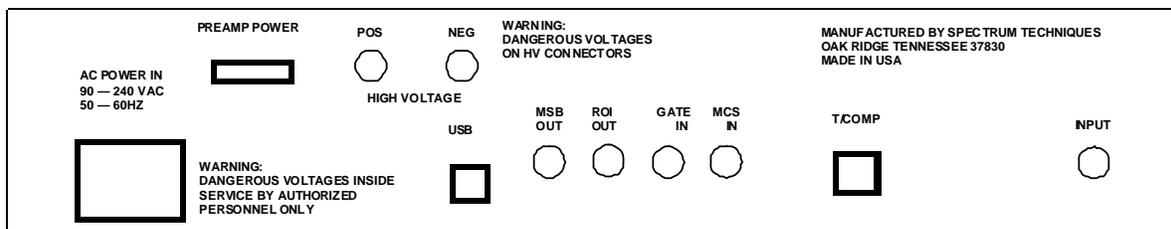
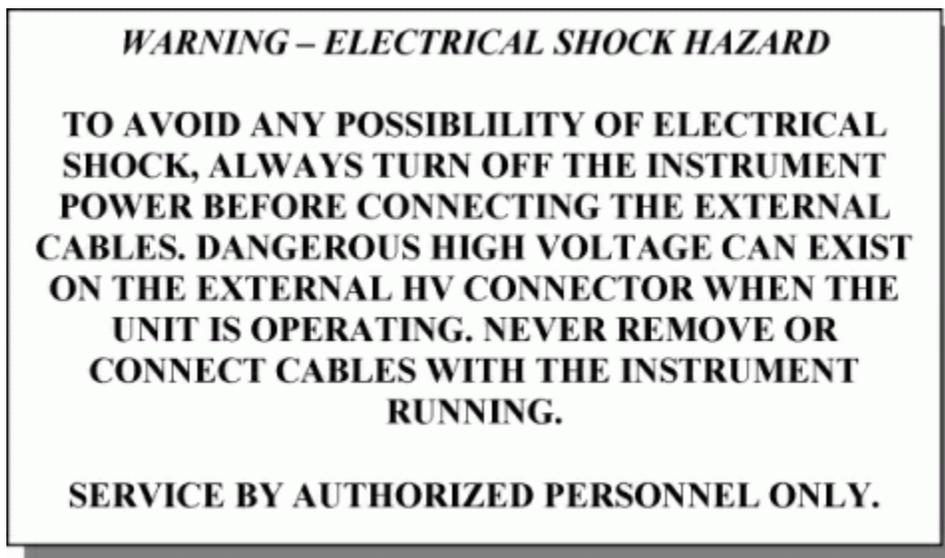
**Library (\*.itm) files**

Isotopes.itm – contains a list of common isotope peaks for use with the IsoMatch function.

### Uninstalling Software

Go to the Windows Start Menu, select Settings, then Control Panel. On the Control Panel, select Add/Remove Software. Find UCS-30, double click and follow the instructions.

### Connections On Rear Panel



Rear Panel

**CAUTION:** Be sure to use the correct high voltage polarity for your device to prevent possible damage to equipment.

**POS HIGH VOLTAGE:** MHV (or optional SHV) connector supplies positive 0 - 2048 volt @ 1mA maximum current to power scintillation detectors. High voltage is fully regulated and computer controlled in 2 volt increments.

**NEG HIGH VOLTAGE:** Negative High Voltage is an Option. If this option is added, the UCS30 can also supply negative 0 - 2048 volt @ 1mA maximum current to power scintillation detector through an MHV (or optional SHV) connector. High voltage is fully regulated and computer controlled in 2 volt increments.

Either the POS HIGH VOLTAGE or NEG HIGH VOLTAGE may be selected for use. Go to the “Settings” menu, then choose the “Amp/HV/ADC Settings” sub menu to gain access to the polarity selection.

**WARNING:** HIGH VOLTAGE must be “OFF” before switching between POS HIGH VOLTAGE or NEG HIGH VOLTAGE. Failure to comply with this WARNING may result in severe instrument damage.

**INPUT:** BNC connector. This input is for signals from a scintillation detector, scintillation preamplifier, or other type detector amplifiers (proportional counter, germanium detector) for eventual processing by the ADC. The internal scintillation preamplifier and also the scintillation amplifier can be bypassed using the “Mode” menu.

**MCS IN:** BNC connector to input positive Multichannel Scaling (MCS) TTL pulses, > 150nsec. 5 MHz maximum rate.

**ROI OUT:** (OPTIONAL) BNC connector supplies a pulse output when data is acquired in a channel marked as a Region of Interest (ROI). The pulse width is adjustable from 100  $\mu$ sec to 25 msec by an internal pot. The pulse amplitude is adjustable from 0 volt to 7.5 volts by an internal pot.

**GATE IN:** BNC connector for connection to external coincidence unit. A positive TTL pulse causes the ADC to accept the next pulse. The Gate pulse must be present before the peak of the input Pulse. Gate pulse width = 50 nsec to 2  $\mu$ sec.

**MSB OUT:** BNC connector to output the most significant MCS bit for Mossbauer Applications. The output pulse period in seconds is equal to the dwell time multiplied by the conversion gain. Used as a trigger for an external device (i.e. constant acceleration drive). Output will begin after the first pass in Mossbauer mode.

**T/COMP:** Modular connector for connection to temperature compensated tube base.

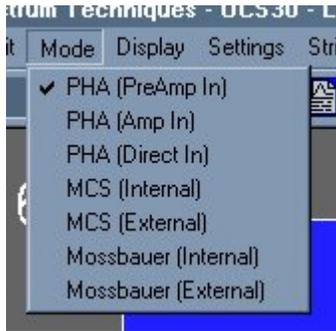
**USB:** Universal Serial Bus connector for communication with computer.

**PREAMP POWER:** DB-9 connector, supplies  $\pm 12$ v power for External preamplifier.

(NOTE: An **OPTIONAL**  $\pm 24\text{v}$  preamplifier power output is available to ensure compatibility with germanium detectors.)

## Analysis Modes

### Pulse Height Analysis (PreAmp In)



This is the normal operating mode for collecting sample gamma emission spectra. The amplitude of each detector pulse is measured by the ADC and stored as an amplitude (energy) spectrum.

The X axis is scaled to the selected channels and the Y axis is scaled for the counts for each channel. Y axis counts that exceed the maximum Y axis value are 'wrapped'; they no longer are scaled to the Y axis, and they appear in a different color.

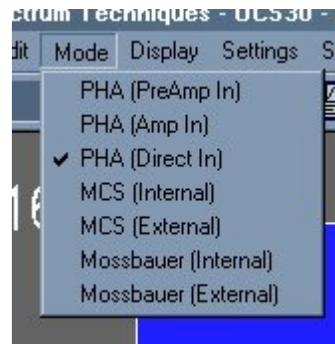
### Pulse Height Analysis (Amp In)



Similar to the 'PHA PreAmp In' operating mode except that the incoming signal bypasses the instrument's internal Pre-Amplifier.

The amplitude of each detector pulse is measured by the ADC and stored as an amplitude (energy) spectrum.

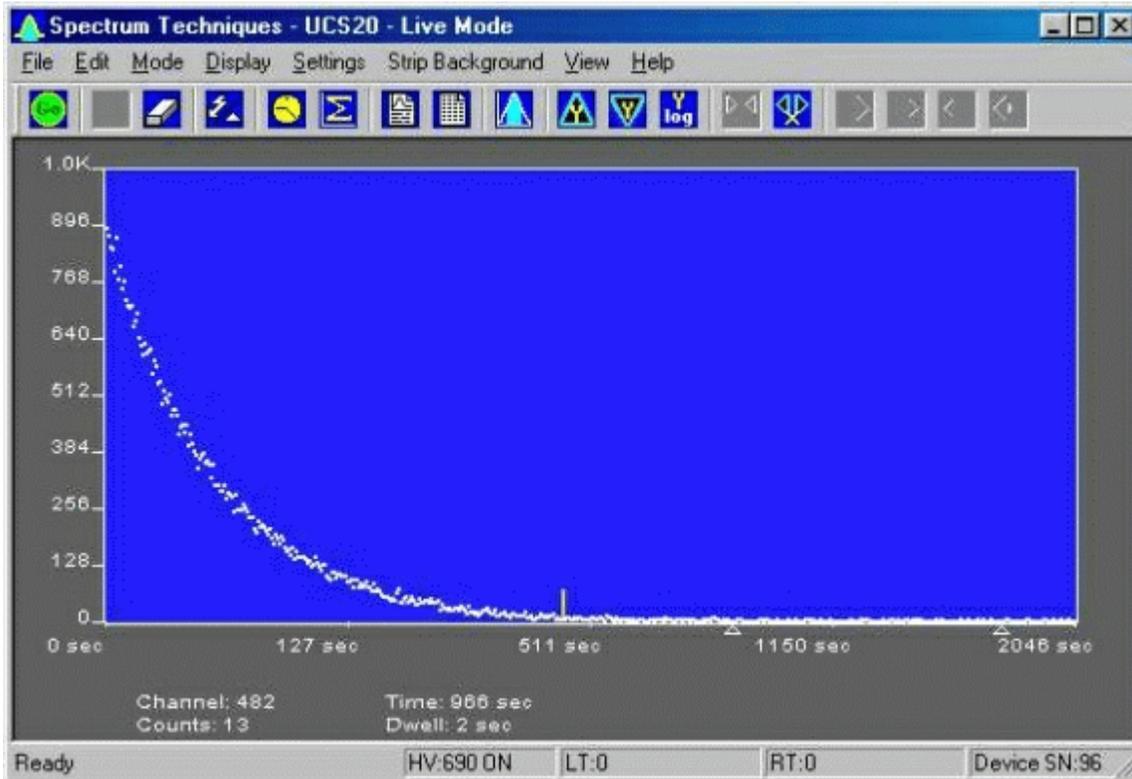
### Pulse Height Analysis (Direct In)



Similar to the 'PHA PreAmp In' operating mode except that the incoming signal bypasses both the instrument's internal Pre-Amplifier and Amplifier.

The amplitude of each detector pulse is measured by the ADC and stored as an amplitude (energy) spectrum.

## Multi Channel Scaling (Internal)

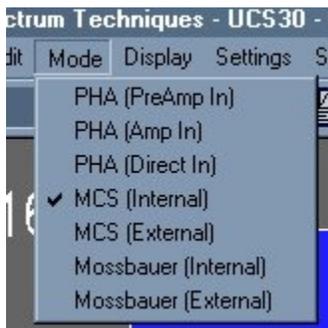


(UCS20 MCS Spectrum shown; UCS30 similar)

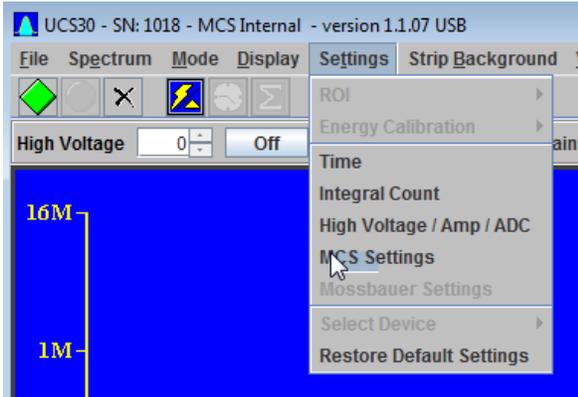
Multi Channel Scaling mode is used for measuring time related phenomena such as half-life decay or single photon counting. The ADC is bypassed and incoming events are routed directly into memory for specific predetermined times (dwell time) and stored in sequential memory locations.

To use this mode, first acquire a spectrum using the Pulse Height Analysis mode. While acquiring the spectrum, adjust the LLD and the ULD to select the energy range of interest (for example, selecting only the 662 keV peak from Cs-137 will eliminate unwanted background and produce a superior decay curve when using a Cs-137/Ba-137 mini-generator.)

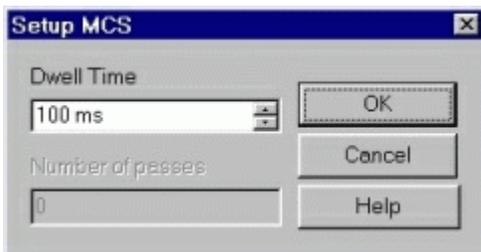
Click the Mode menu and select MCS



Click the Settings menu and select MCS



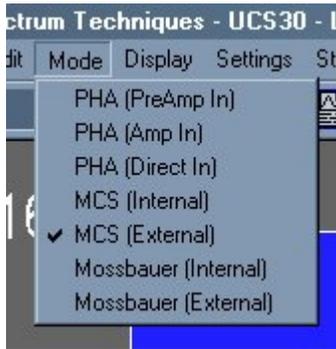
The Setup MCS Dwell Time dialog box will appear:



Enter the Dwell Time. This time is for each memory location (channel). Remember the total pass time will be equal to (Conversion Gain x Dwell Time).

Erase any current memory data and click **START COUNTS**. The UCS-30 will proceed to count incoming events for the selected dwell time, store the total in the first channel location, reset the counter and repeat the cycle storing each total count in sequential channels.

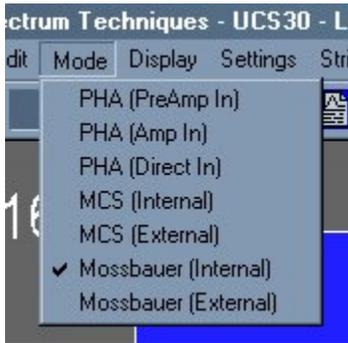
## External Multi Channel Scaling



If you wish to use an external pulse generation system such as a coincidence circuit, it will be necessary to bypass the on-board amplifier and discriminators. Connect the external counts connector to the Ext MCS connector on the back of the instrument and select the menu item MODE, then select External MCS.

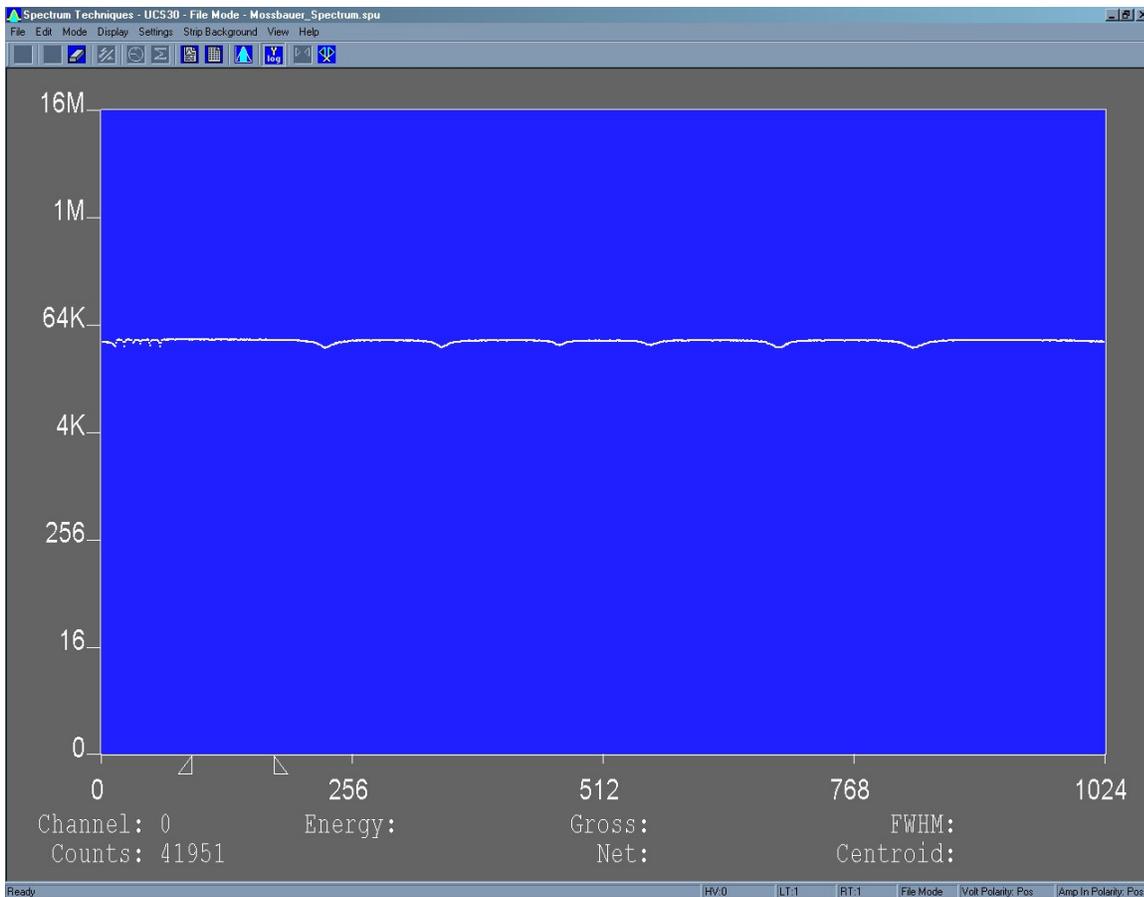
When operating in this mode, the MCS input requires positive TTL signals ( $>2.5\text{v}$ ,  $>150\text{ ns}$  duration).

## Mossbauer (Internal)

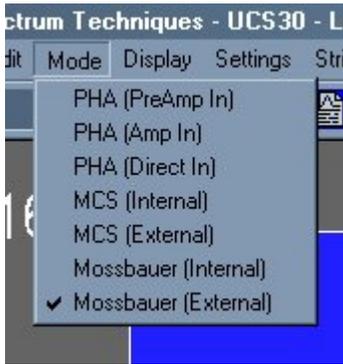


This mode uses the internal preamp. Connect the signal into the **INPUT** BNC connector. The Mossbauer mode has variable dwell time ranging from 100  $\mu$ Sec to 6 Sec. A Preset number of passes can be set to the desired number or left at zero (0) for infinite passes.

The following is the Mossbauer spectrum of a Co-57 source with an enriched Fe-57 absorber, showing nuclear Zeeman splitting.

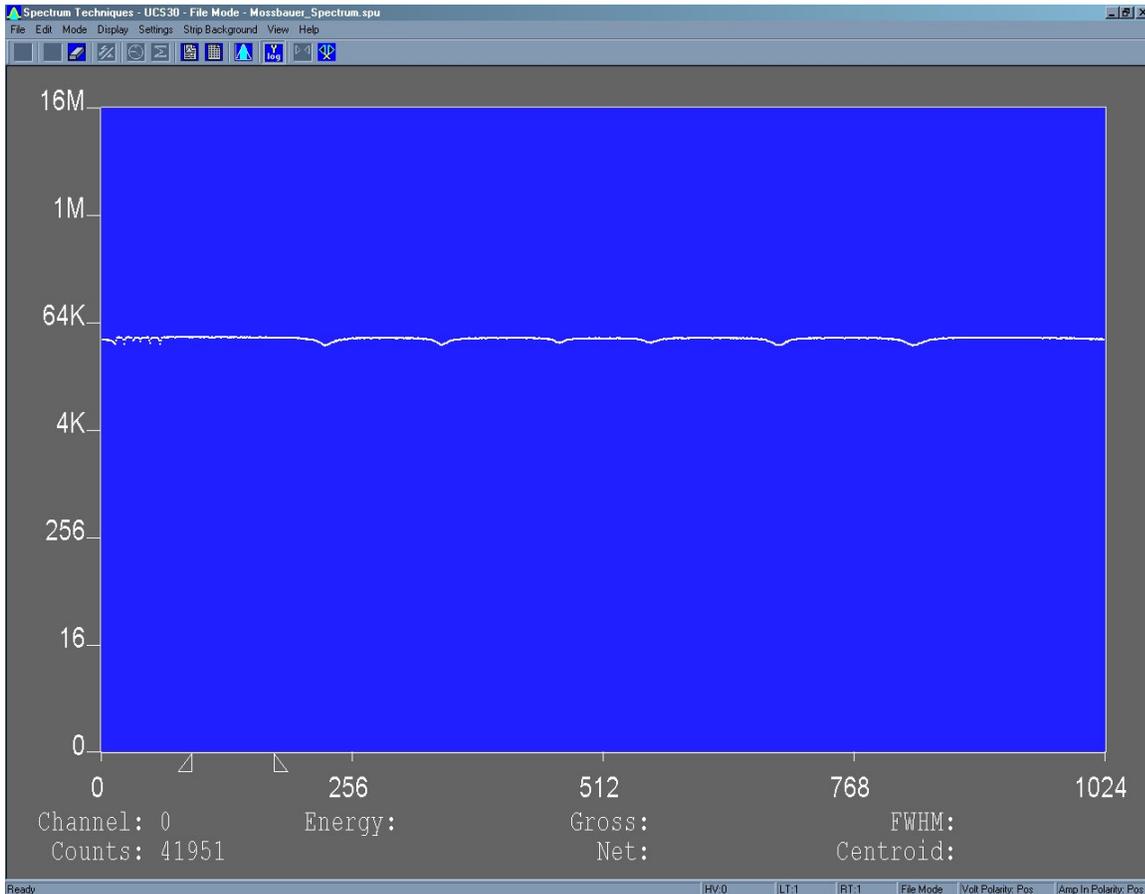


## Mossbauer (External)



This mode requires the use of an external amplifier. The signal must connect to the **MCS INPUT** BNC connector. The Mossbauer External mode has variable dwell time ranging from 100  $\mu$ Sec to 6 Sec. A Preset number of passes can be set to the desired number or left at zero (0) for infinite passes.

The following is the Mossbauer spectrum of a Co-57 source with an enriched Fe-57 absorber, showing nuclear Zeeman splitting.



# Operation

## Live Mode



The software starts up in the Live Mode. This mode uses the USB to communicate with the instrument.

If you access the File Menu and click on Open, a new window appears which looks like the current window, except that the title bar shows 'File Mode' instead of 'Live Mode'. File mode does not communicate with the

instrument and is used only to view and manipulate files that have been saved to disk.

## File Mode



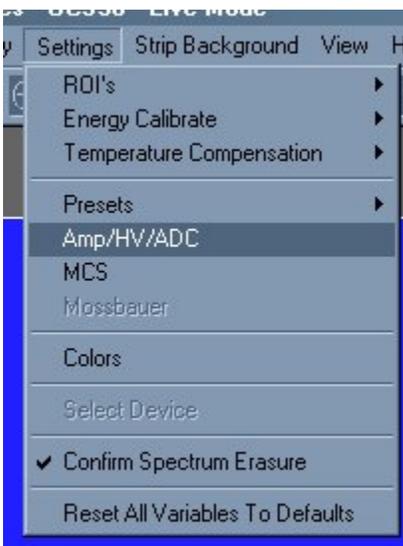
File Mode is accessible from the live mode by going to the File Menu and clicking on Open. Select the file you want to view. Some functions, which have no use when viewing files, are disabled in the Menus and the Toolbar.

## Amp/HV/ADC

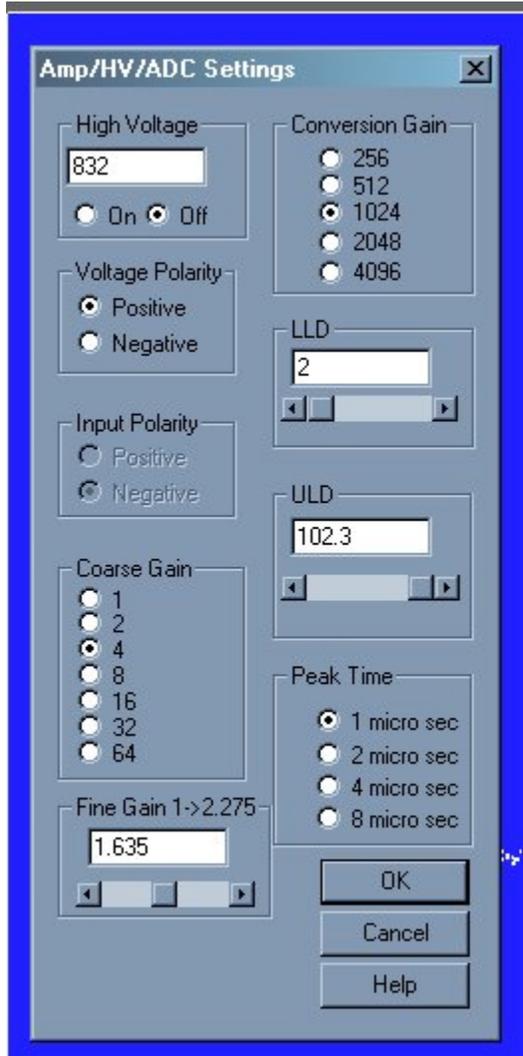
Click the Amp/HV/ADC Button on the toolbar:



Or use the settings menu and click on Amp/HV/ADC



The Amp/HV/ADC dialog box will appear.



Adjustments may be made to the amplification, high voltage, conversion gain, low level discriminator, and the high level discriminator.

Selecting OK will cause these values to be written to the UCS-30 instrument.

# Configuring System Parameters:

Once the program is running it will be necessary to configure the system parameters for correct operation and calibration.

Place a gamma emitting check source near the detector face. Cesium-137 (Cs-137) is a good choice. It has a single peak at 662 keV.

Click on **Settings**, then click on **Amp/HV/ADC**

Set the high voltage to the voltage as listed by the detector manufacturer. As an example, set the high voltage to positive 600 volts; click **ON**.

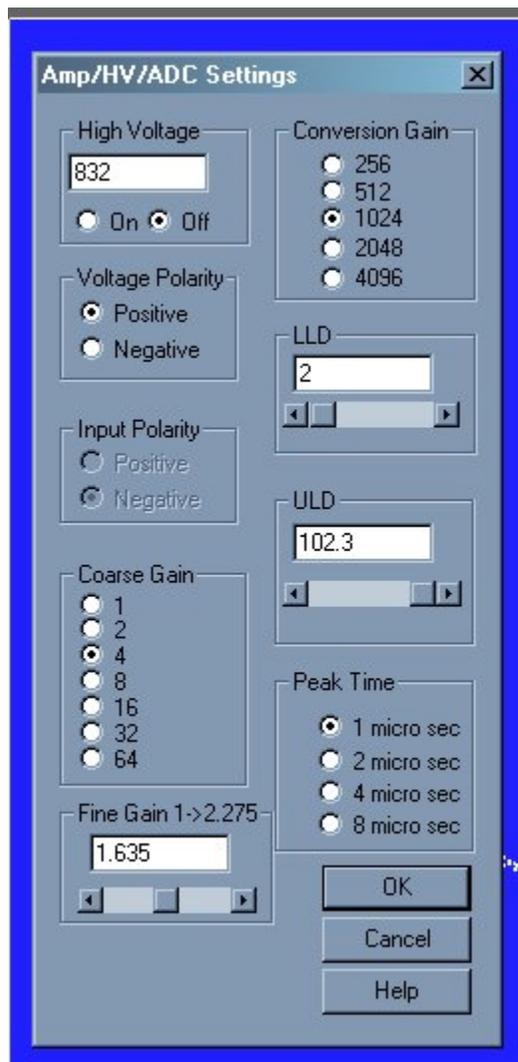
***DO NOT** exceed the maximum high voltage rating of the detector, usually 1200 volts.*

Set the amplifier **COARSE GAIN** to 8, and set the **FINE GAIN** to 1 as a starting position. Click on **OK**, to set adjustments and exit the menu.

**Start** the data acquisition and adjust the **amplifier gain** until the 662 keV peak is approximately mid-scale.

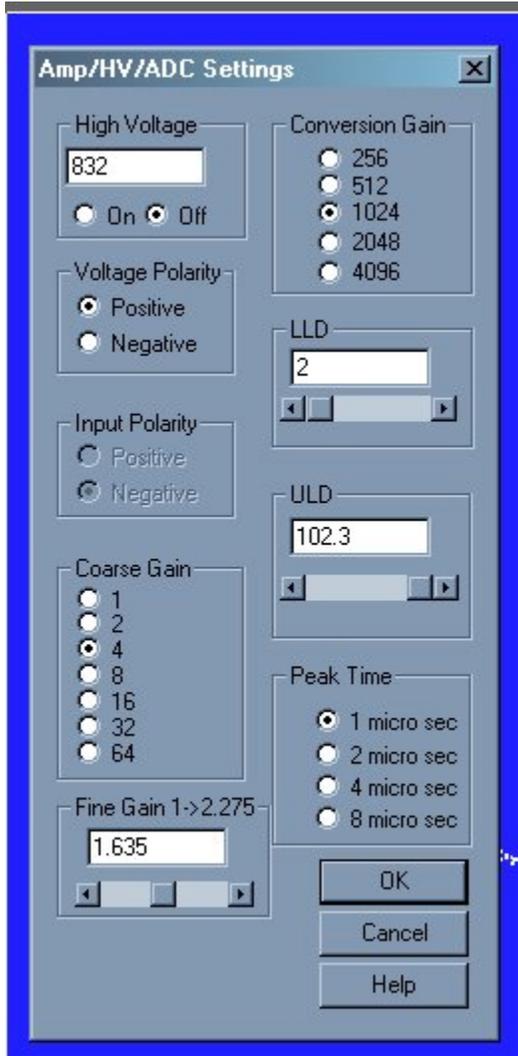
Once the acquisition is started, you may enter the **Amp/HV/ADC** menu and make adjustments while viewing the spectrum. This will allow you to position the peak in the desired channels.

## High Voltage



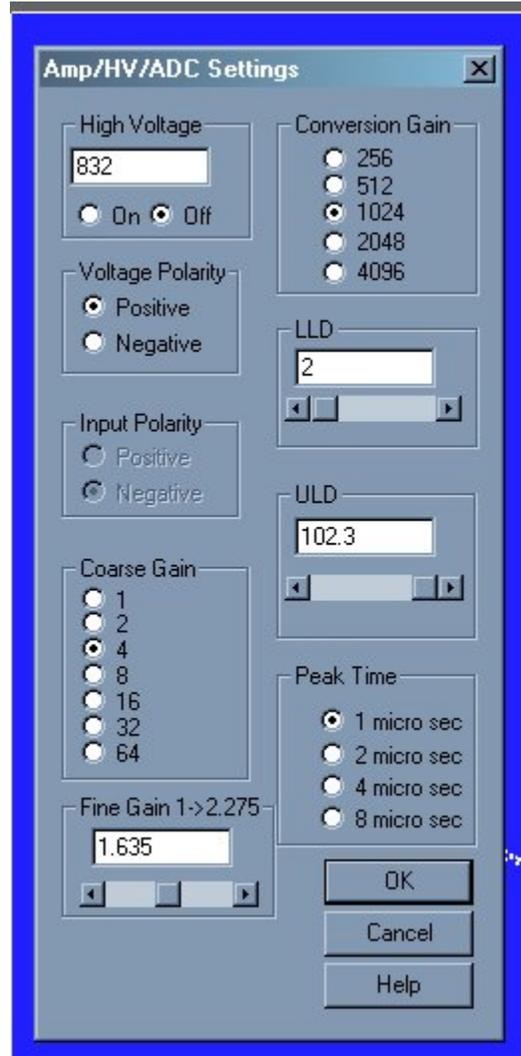
High Voltage may be entered directly in the text box or may be scrolled to the value desired. A warning will be issued if you attempt to input a value higher than 1200 volts, since this is the highest value that many probes can tolerate without damage. If you know that your probe can accept higher than 1200 volts, you may increase the voltage up to 2048 volts.

## Amplifier Coarse Gain



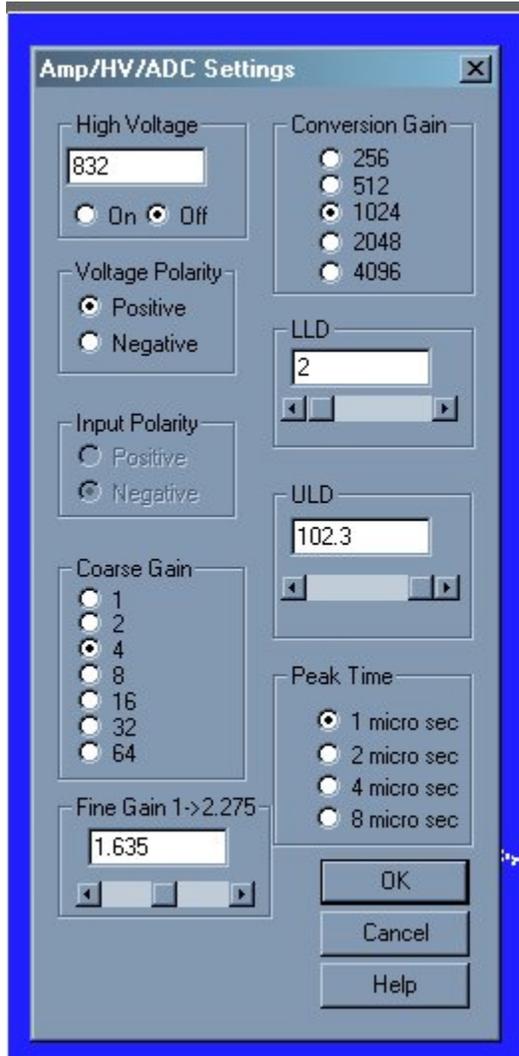
Amplifier coarse gain may be set by clicking the radio-button next to the desired multiplier.

## Amplifier Fine Gain



Amplifier fine gain may be directly entered as a multiplier value between 1.0 and 2.275 in 0.005 increments.

## ADC Conversion Gain

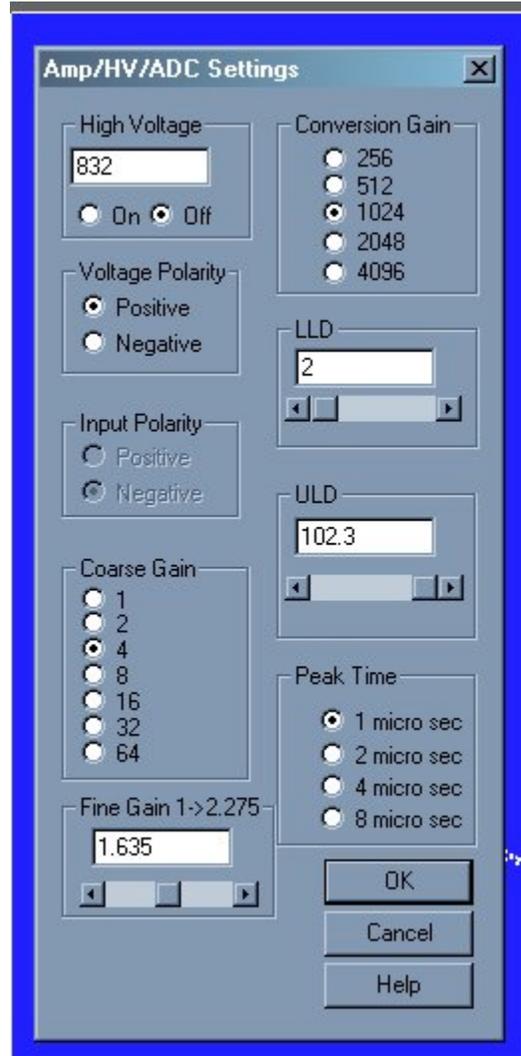


Conversion Gain represents the number of channels that will be sampled and displayed on the screen. Smaller values save as smaller files

The conversion gain default setting is maximum channels. This is preferred for most scintillation detector applications and generally no adjustment is required.

For certain applications, such as alpha spectroscopy, it may be necessary to change this parameter to either 256, 512, 1024, 2048 or 4096 channels.

## Lower and Upper Level Discriminators



LLD and ULD, Lower Level Discriminator, and Upper Level Discriminator, allow the user to set a value between 0 and 102.3 (roughly percent) that cuts off the input signal before it gets to the ADC. The LLD is often used to block high-count signals (noise) in the low range that are not of interest, but require excessive time to sample. The ULD may be set up to 102.3.

Low level discrimination (LLD) may be scrolled or directly entered.

Upper level discrimination (ULD) may be scrolled or directly entered.

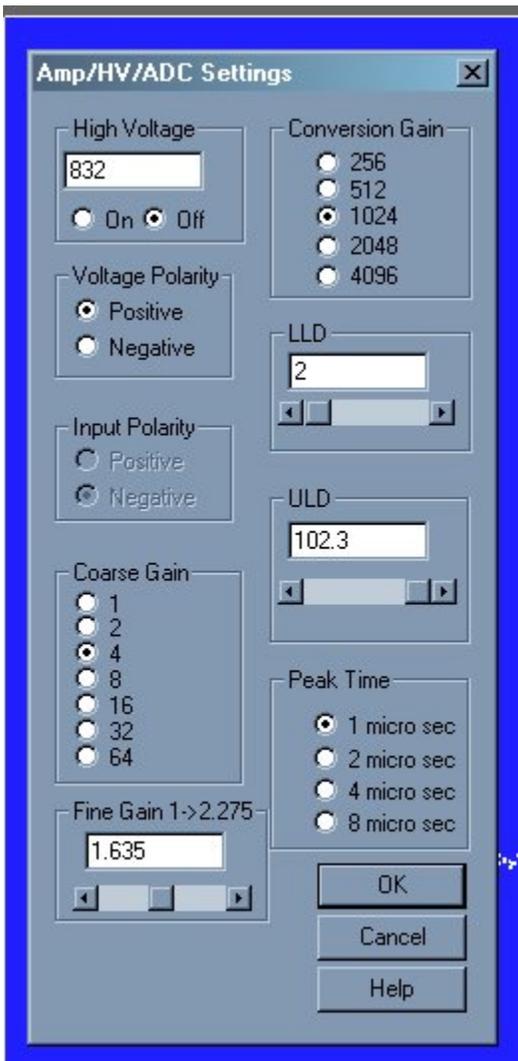
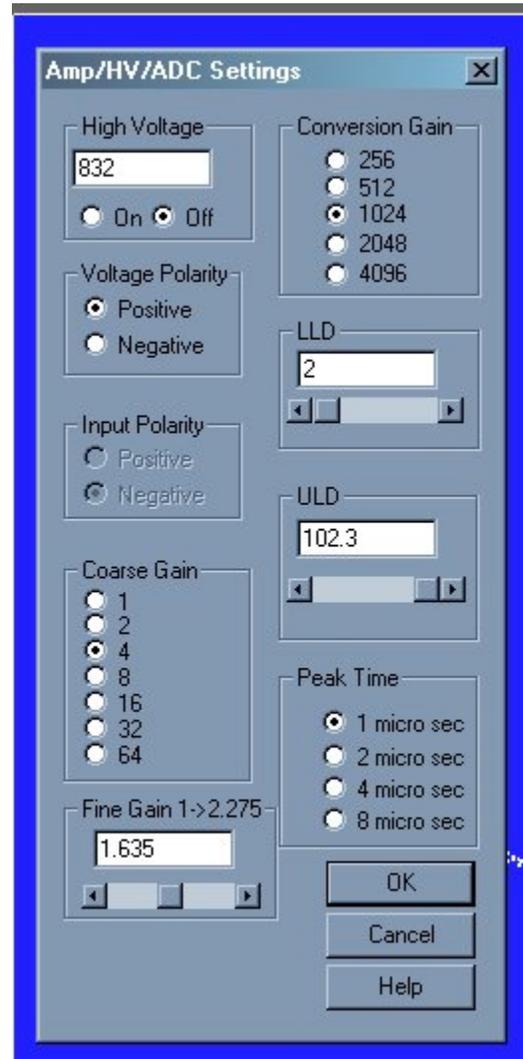
The ability to switch between positive and negative high voltage polarities is an add-on option.



An alternative method to change the LLD and ULD is to use the mouse to move the triangles under the X axis. Move the mouse over the triangle to be moved, press the left button, drag the triangle and release it where desired. The software will not allow the LLD and the ULD to be set outside appropriate ranges.

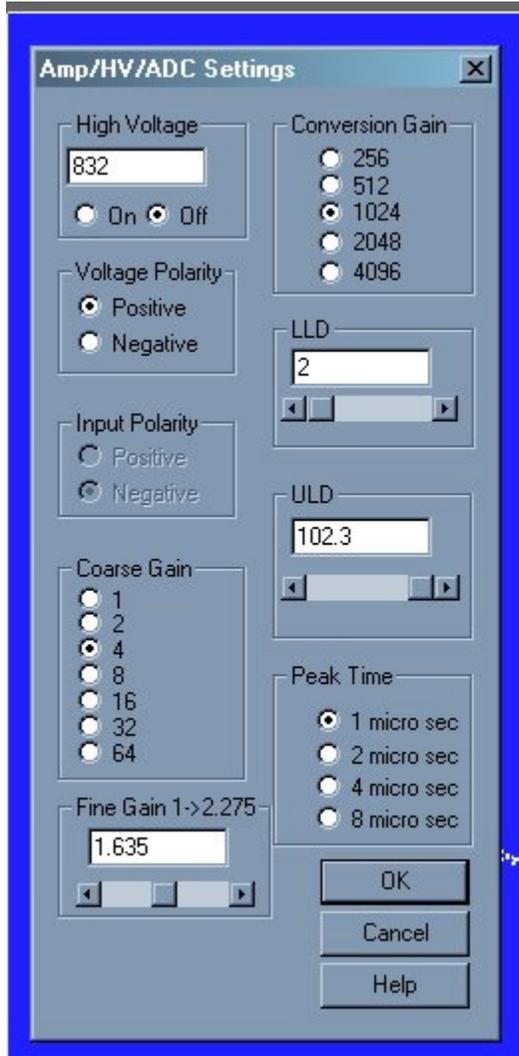
### Input Polarity

### Voltage Polarity



Some detectors require a positive input polarity. This option is only available in PHA Amp In mode.

## Peak Time Shaping



Amplifier Peaking Times of 1, 2, 4, or 8 microseconds are selectable in Amp In mode only.

Peaking times longer than 1 microsecond are useful with solid state detectors such as Ge(Li) or HPGE detectors.

## Presets

### Preset Time

The real time count and the live time count may be changed using the Preset function.

Click the Preset Time Button on the toolbar:



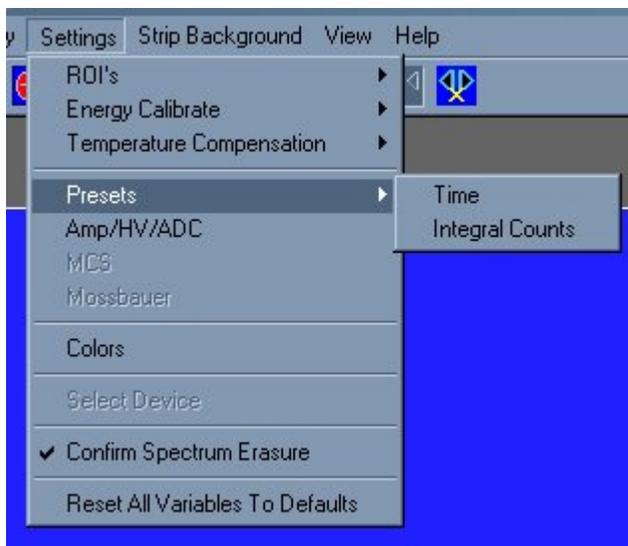
### Preset Integral

The instrument can be set to stop automatically after a ROI integral.

Click the Preset Integral Button on the toolbar:



Or use the settings menu and click on Presets:



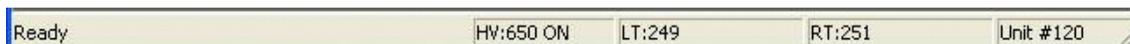
## Preset Time



**Preset Live Time** provides automatic correction for counting losses caused by the system deadtime, or the amount of time required by the system to process pulses. Events which occur during the pulse processing cycle are lost to the system so the timer is automatically updated to compensate for these losses. When operating at excessively high count-rates the deadtime meter will indicate a high value and the real counting time may be more than doubled. Increasing the LLD setting can help reduce some high deadtime effects.

**Preset Real Time** sets the counting timer to run for actual clocktime and makes no correction for losses due to deadtime effects.

Click on **Settings**, click on **Presets**. Enter the **LIVE** or **REAL** time in the correct box. Click on **OK**, to set adjustment and exit menu.



Both the **LIVE TIME** and **REAL TIME** values are displayed on the UCS-30 status bar as LT and RT. These values are saved in the file during data storage.

## Preset Integral



## Set Integral

To set an integral count it is necessary to first establish a ROI and then position the marker within the region.

Selecting an ROI and setting a value other than 0 in preset integral will cause the system to STOP counting when the total counts of all the channels within the ROI reaches that value.

## Go, Stop and Erase

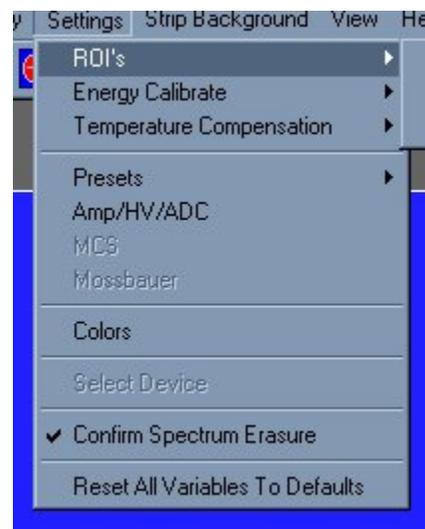


**Go**, **Stop** and **Erase** functions are accessed with the Tool Bar buttons. Clicking on **Start** begins data collection. Clicking on **Stop** ends data collection. Clicking on **Erase** sets each channel's data to zero. Additionally, three 'hot key' combination are defined as shortcuts for data acquisition functions. Pressing the appropriate action key while pressing the 'Ctrl' and 'Shift' keys will provide **Go**, **Stop** and **Erase** action. To **Go** press '*Ctrl+Shift+A*'; to **Stop** press '*Ctrl+Shift+S*'; and to **Erase** press '*Ctrl+Shift+E*'.

## Region of Interest (ROI)



**Region of interest (ROI)** selection is an advanced feature which provides instantaneous computation of peak gross and net counts. These values may be used along with isotope decay tables and detection efficiency to calculate absolute or relative isotopic activities. ROIs must not overlap and need to be separated by at least one channel for correct area calculation. Up to 16 different ROIs are possible using the color selector from the pull down **Settings** menu.



### Set ROI

To set an ROI around a peak, click the ROI button on the Tool Bar. Click the left mouse button at the beginning of the ROI, hold down the left mouse button and drag the marker to the other side of the peak, release mouse button.

### Clear ROI

Move marker to the ROI to be cleared. Open the Setting Menu, open ROI and select Clear ROI.

### Gross and Net Count

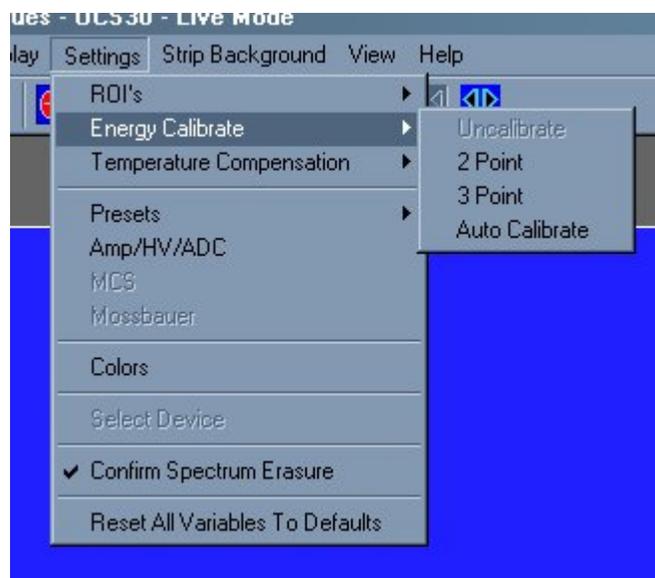
When the marker is positioned in a region of interest (ROI), the UCS-30 software automatically calculates the **Gross** and **Net**

area of the region. In order to minimize statistical effects at the **ROI** endpoints, a 3-point averaging technique is applied. The contents of channels  $(n-1)$ ,  $(n)$ , and  $(n+1)$  are summed and averaged to derive the content of the endpoint channel for the net area computation. A linear interpolation is performed between these averaged endpoint values and counts below this interpolation are subtracted to arrive at the **Net** area of the peak. Gross counts is the sum of all channels in the **ROI**.

Position the marker in the peak of interest. The **Gross** and **Net** areas are automatically computed and displayed on the spectrum screen.

## Functions

### Energy Calibration



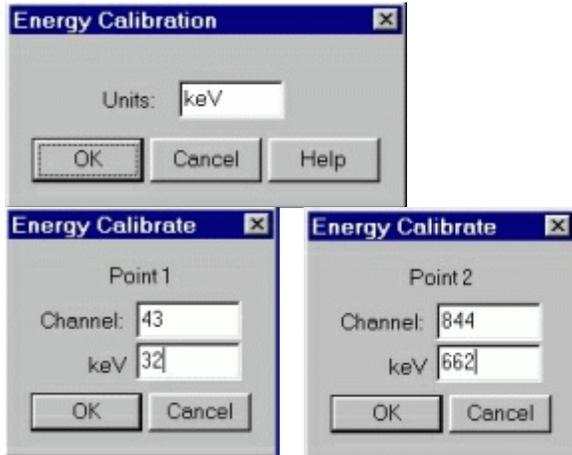
The energy calibration feature allows the marker to read directly in energy units. Two calibration functions are possible, a 2-point linear, or a 3-point quadratic fit.

In order to perform an energy calibration, it is first necessary to acquire a spectrum using known isotopes. Cs-137 together with Co-60 works well for many applications, producing gamma lines at 32 keV, 662 keV, 1173 keV and 1332 keV.

Select **2-point** or **3-point** mode and enter the calibration units to be used, (keV or MeV). Position the marker at the highest channel of the first peak and enter the peak energy value. Move the marker to the high point on the second peak to be used for the calibration, enter energy number. If a 3-point calibration is required, continue by moving the marker to the peak channel of the third peak, enter its energy and click OK. The system will now be calibrated and the marker position will read directly in energy.

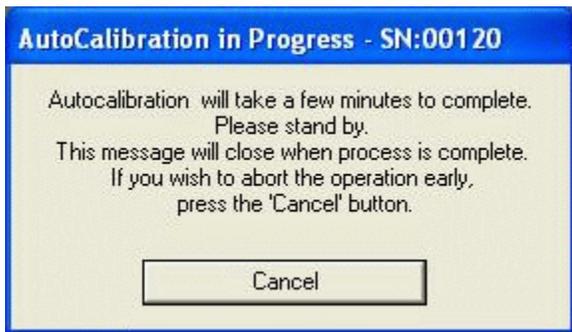
To return to the channel number mode, click on **Settings**, click on **Uncalibrate**.

Energy Calibration may also be selected using the right mouse button.



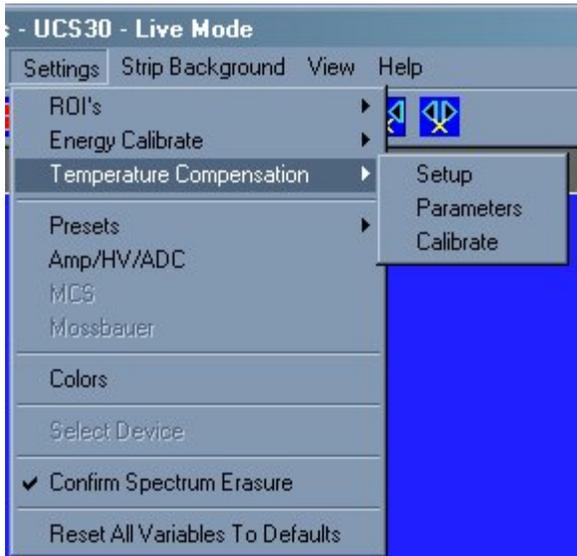
information dialog box is displayed which advises to wait for completion and provides an opportunity to cancel the calibration. Pressing of the Cancel button will result in the auto-calibration process being aborted and the high voltage setting being reset to zero. If allowed to work to completion, the gains and voltage will be left at the determined calibration settings and the spectrum scale will be displayed in energy.

**Auto Calibrate** is a convenience provided for users working in the under 1000 keV energy range. Selecting **Auto Calibrate** will initiate an acquisition sequence that attempts to determine optimum detector voltage and gain settings for a calibrated energy spectrum display. This calibration is specifically designed to place the primary peak of a **Cesium-137** source at a point approximately 65% of the x-axis scale. Once located, the energy calibration coefficients are calculated to provide a two point calibration (32 and 662 keV. Use of other sources will result in erroneous calibration.



The calibration sequence can require a few minutes to complete. In the absence of an adequate source or improper cable connection, the process may not succeed. Once **Auto Calibrate** begins, an

# Temperature Compensation

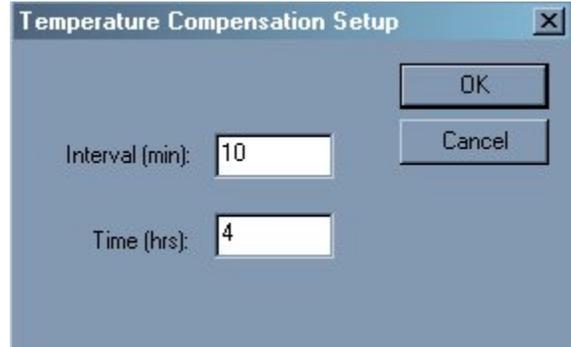


---THIS FUNCTION IS NOT CURRENTLY AVAILABLE ---

The temperature compensation feature allows the UCS 30 to automatically adjust the fine high voltage to correct for temperature variation.

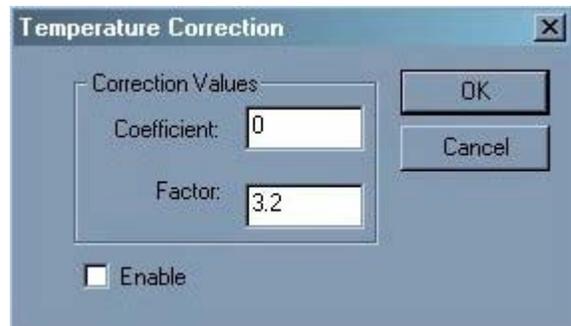
In order to perform temperature compensation, the fine high voltage factor (measured in channels/step) and temperature coefficient (measured in channels / degree celsius) must be known. These can be provided by the use in the **Parameters** menu, or found by allowing the UCS-30 to **calibrate** for temperature compensation using a cesium source.

## Setup



The setup menu provides the UCS 30 with the length of time it should monitor temperature variations to calculate the temperature coefficient. The interval, which must be set to 5~60 minutes, is how often the UCS 30 measures the temperature and cesium peak. The time, which must be set to 4~24 hours, is how long the UCS 30 will stay in calibration mode.

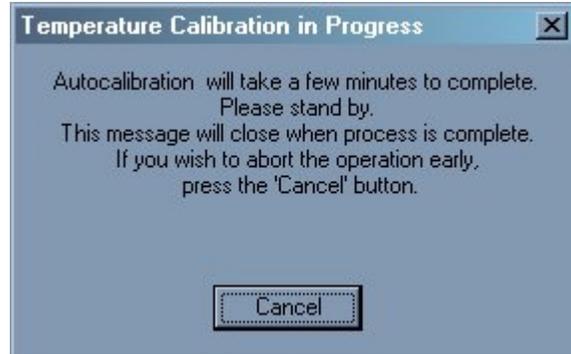
## Parameters



The fine high voltage factor (measured in channels/step) and temperature coefficient (measured in channels / degree celsius) can be entered in the parameters menu. Also, temperature compensation may be enabled in this dialog box by clicking the enable checkbox.

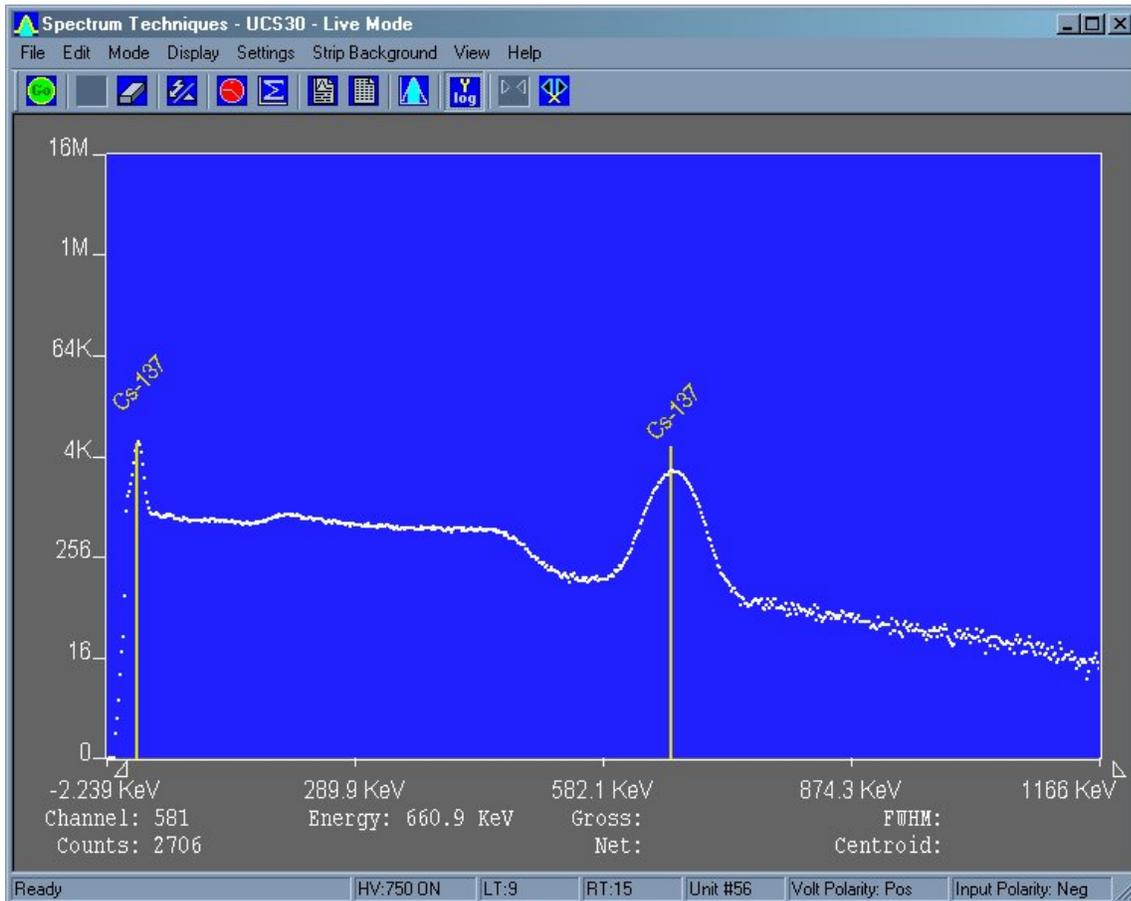
The parameters are automatically changed and temperature compensation is enabled after calibrating for temperature compensation.

Selecting **calibrate** will initiate an acquisition sequence that attempts to determine the compensation parameters. First it attempts to **AutoCalibrate** the system. Once energy calibrated, the UCS 30 will attempt to find the temperature compensation parameters by finding the cesium peak at the specified interval over the specified time.



Since the calibration will take several hours, an information dialog box is displayed which advises to wait for completion and provides an opportunity to cancel the calibration. Pressing of the Cancel button will result in the temperature compensation calibration process being aborted.

## Isotope Matching



## Displaying Isotope Peaks

Isotope peaks may be indicated on calibrated spectra. These peaks are selected from a list provided by selecting the **Display** menu and clicking on **Iso Match**. The following dialog box will be displayed:



Click the isotopes peaks in the window that you want to display. These will be highlighted to indicate selection. When your list is complete, click Okay to display them.

## Editing the Iso Match list

Select the **Edit** menu and click **Iso Match**. The following dialog box will be displayed:





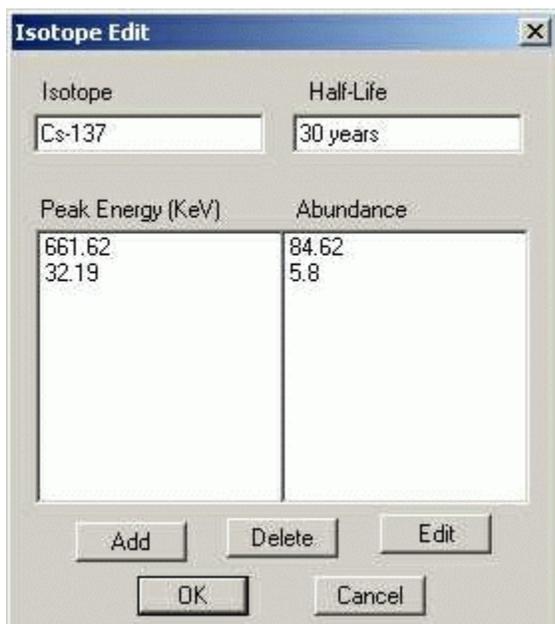
**IsoMatch Library NOT loaded.**



**IsoMatch Library IS loaded**

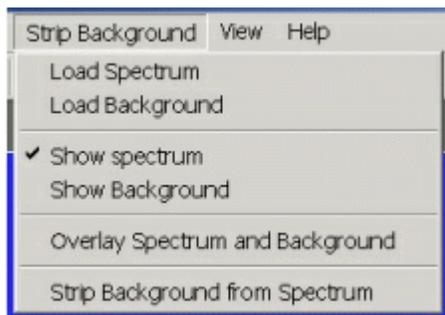
The dialog box top window labeled 'Select an existing isotope' will be empty unless an Iso Match library has been loaded. If a library has been loaded, you can select one of the entries from the window, if a library has not been loaded, or you want to add an entry to the list, enter the name in the second window titled 'or enter an isotope name'. Enter the number of peaks you want to add for this isotope in the third box labeled 'Enter number of peaks [10 max]' and click on Edit.

Further dialog boxes will appear that allow you to enter peak(s) for the isotope.



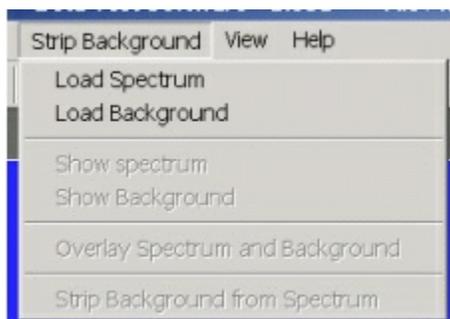
If you want to save the Iso Match to a disk file, open the File Menu and click on Save Library.

## Strip Background



Allows the user to load a spectrum and a background and then strip the background from the spectrum.

## Strip Background

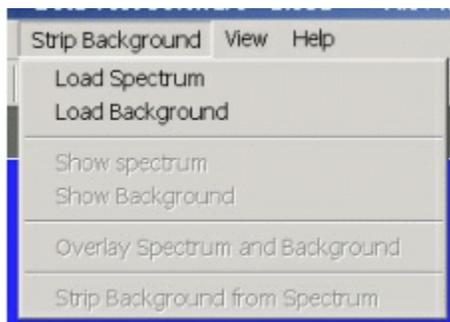


The Strip Background option is available only in the File Mode. The user may load two files (Spectrum and Background) and subtract the second file from the first. The portion subtracted is based on a time adjustment to the data in the second file. For example if the first file was measured with 100 seconds live time and the second file was measured with 200 seconds live time, then the data in the second file is divided by 2 (200 seconds / 100 seconds) before it is subtracted.

### **Background Subtraction**

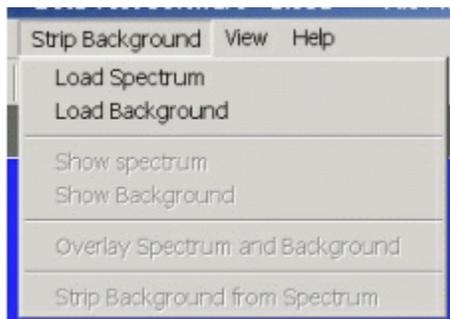
This is a special case of spectrum stripping. Collect a background sample spectrum, usually for a long collection time. Load this spectrum as Background and click on 'Strip Background from Spectrum.' The live time fraction of the background is subtracted from spectrum. This provides a convenient method of removing naturally occurring background from a sample spectrum and can be very useful when working with low level environmental samples.

## Load Spectrum



Click on **Load Spectrum** and in the **File Dialog Box** that opens, select the spectrum you intend to have the background stripped from. For example, the spectrum may be taken for an isotope; the background may be the readings with no isotope present.

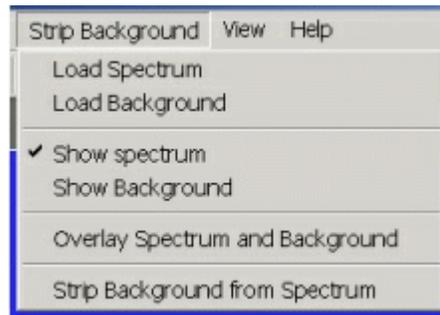
## Load Background



Click on **Load background** and in the **File Dialog Box** that opens, select the background you intend to strip from the first. For example,

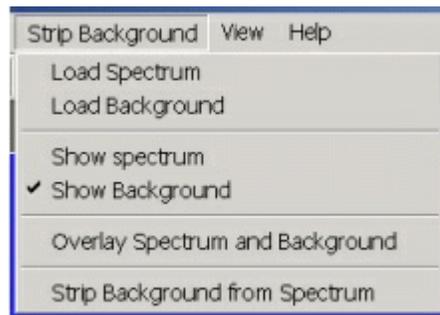
the spectrum may be taken for an isotope; the background may be readings with no isotope present.

## Show Spectrum



Click **Show Spectrum** to view spectrum.

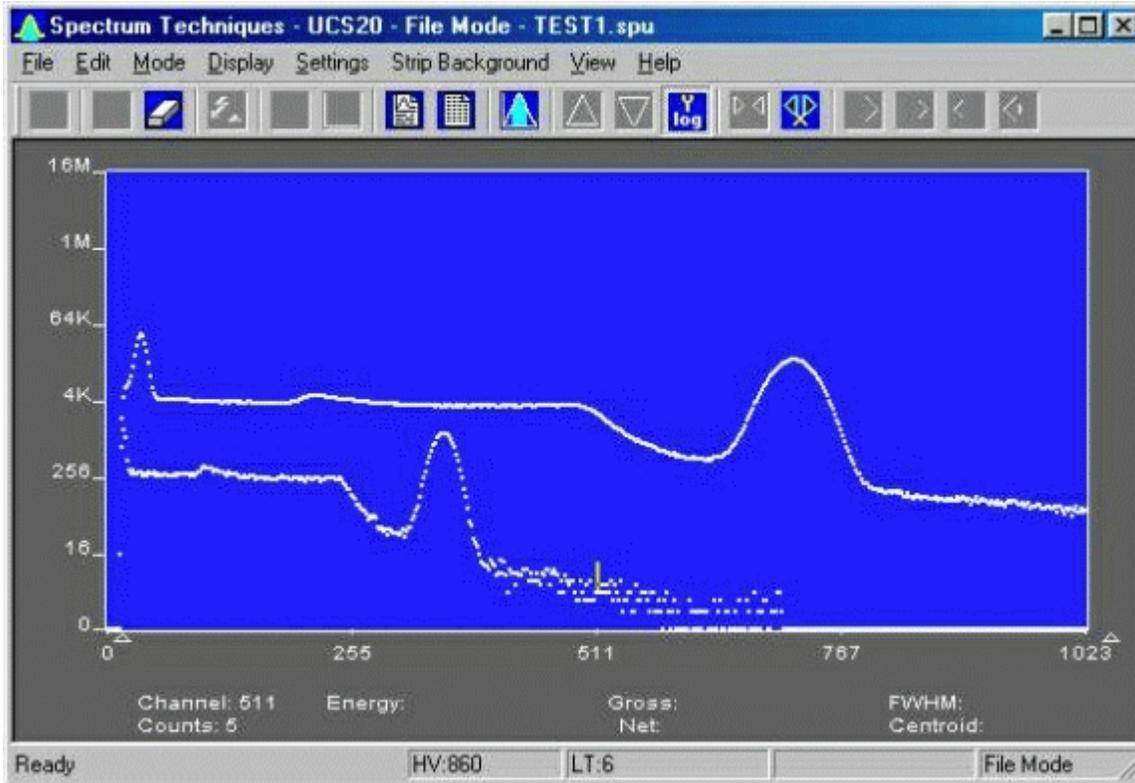
## Show Background



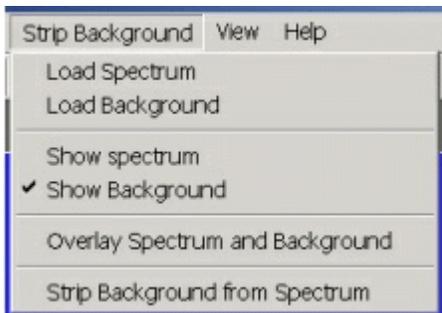
Click **Show Background** to view background.

## Overlay Spectra

Click **Overlay Spectra** to view the spectrum and the background at the same time.



## Strip Background from Spectrum



Click **Strip Background from Spectrum** to subtract the two spectra, where the background is corrected for the difference in the data collection time to give a correct proportion. As an example, if the background count time is 10 minutes and the sample count time is 60 minutes, then the **Strip Background from Spectrum** function will subtract  $1/6$  (10 minutes background count time/60 minutes sample count time) of the background counts from the sample spectrum.

## Data Smoothing

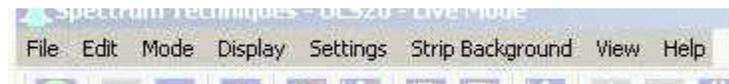


Click **Smooth Data** to perform a 3-point averaging of the data currently being displayed. The function uses the following algorithm to average data in each channel, where 'n' is the channel number.

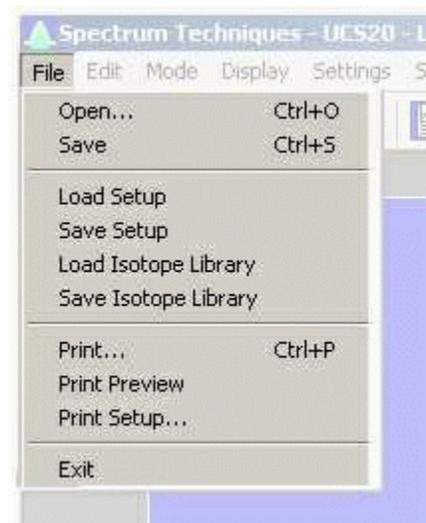
$$\frac{(n-1)+(n)+(n+1)}{3}$$

## Menu Bar

Many advanced functions are possible via the pulldown menus. This section describes each operation in the sequence they appear. Black letters indicate the function is operational, gray indicates not-operational, highlighted indicates the function to be activated.



## File



## File Open

**File Open** allows the user to open data files. A new instance of the UCS-30 application in the **File Mode** is generated.

## File Save

The spectrum data and the associated setup and experiment data are saved to a \*.spu file.

## File Load Setup

Used if power has been turned off to the USC30, **Load Setup** loads a previously saved setup file and quickly restores the analyzer to its previous operating condition.

***High Voltage must be turned on after loading setup !***

## File Save Setup

Once the UCS-30 has been setup and calibrated, **Save Setup** stores all operating parameters as a disk file for subsequent retrieval. See **Load Setup** description, above, for this procedure to restore the UCS30 to a previous condition.

## File Load Library

Allows loading of an Iso Match library file (\*.itm).

## File Save Library

Allows saving of an Iso Match library file (\*.itm).

## File Print

Allows the user to print the displayed spectrum.

## File Print Preview

Allows the user to preview the spectrum as it will be printed.

## File Print Setup

Allows the user to adjust the printer parameters before printing.

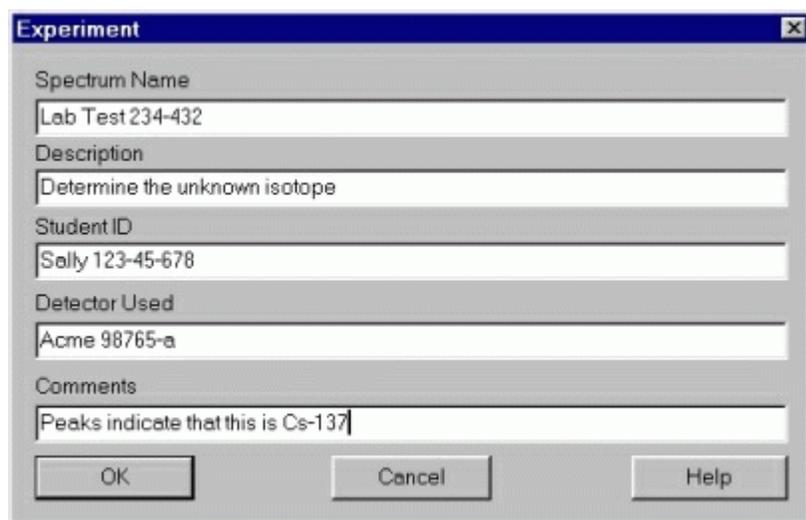
## File Exit

Closes the application.

## Edit



## Edit Experiment

A screenshot of the 'Experiment' dialog box. The dialog box has a title bar with 'Experiment' and a close button. It contains several text input fields: 'Spectrum Name' with the text 'Lab Test 234-432', 'Description' with 'Determine the unknown isotope', 'Student ID' with 'Sally 123-45-678', 'Detector Used' with 'Acme 98765-a', and 'Comments' with 'Peaks indicate that this is Cs-137'. At the bottom, there are three buttons: 'OK', 'Cancel', and 'Help'.

**Edit Experiment** provides a means of inserting text into spectral file headers for referencing specific measurements. This text is saved along with data and parameter information in .SPE and .TSV files, and it is used for the Peak Report and the Data Report. The comments field saves a maximum of 50 characters.

Enter the desired text into the dialog box and click OK when finished.

## Edit Iso Match

### Editing the Iso Match list

Select the **Edit** menu and click **Iso Match**. The following dialog box will be displayed:





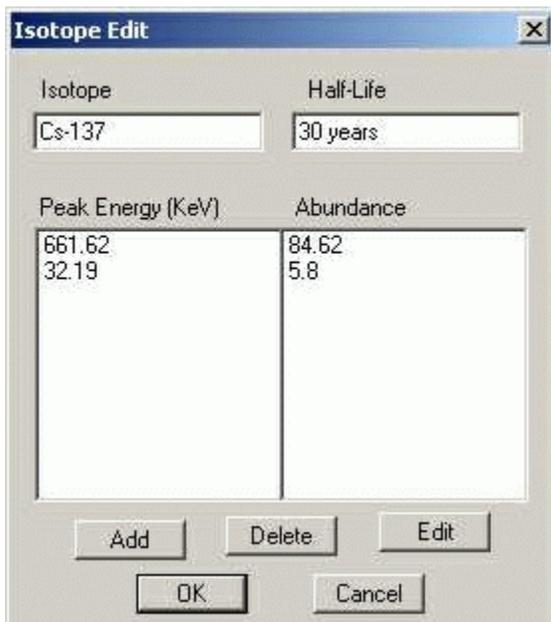
Iso Match Library NOT loaded.



Iso Match Library IS loaded

The dialog box top window labeled 'Select an existing isotope' will be empty unless an Iso Match library has been loaded. If a library has been loaded, you can select one of the entries from the window, if a library has not been loaded, or you want to add an entry to the list, enter the name in the second window titled 'or enter an isotope name'. Enter the number of peaks you want to add for this isotope in the third box labeled 'Enter number of peaks [10 max]' and click on Edit.

Further dialog boxes will appear that allow you to enter peak(s) for the isotope.

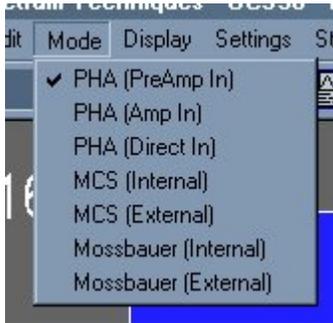


If you want to save the Iso Match to a disk file, open the File Menu and click on Save Library.

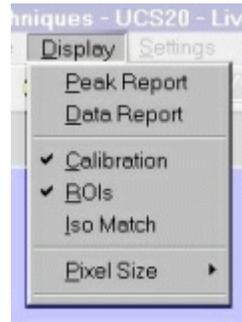
## Edit Smooth Data

**Edit Smooth Data** allows the user to apply a three-point smoothing algorithm to the displayed data.

### Mode



### Display



## Display Peak Report

If regions of interest have been set around peaks in a spectrum, the **Peak Report** provides a convenient method of displaying peak information in tabular form. Readout will be in energy units if the energy calibration is active.

## Display Data Report

The **Data Report** includes all hardware setting, counting parameters and spectrum data. ROI data is reported by lower and upper channels set, gross, net, FWHM, centroid, all channels and corresponding counts.

## Display Calibration

**Display Calibration** allows the user to switch between on/off in calibration mode and channel numbers or energy is displayed on the horizontal line.

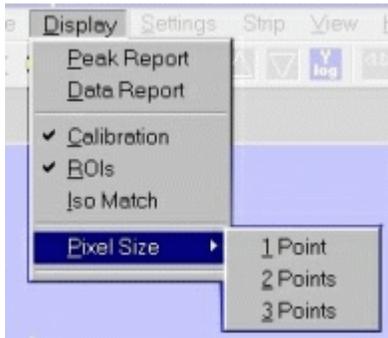
## Display ROIs

**Display ROIs** lets the user toggle between displaying and not displaying the ROIs.

## Display Iso Match

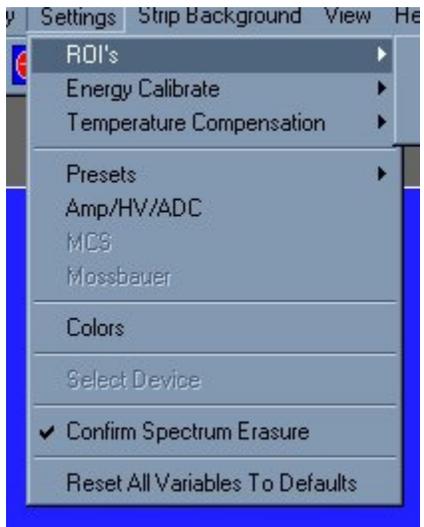
**Display Iso Match** lets the user toggle between displaying and not displaying the Iso Match peaks.

## Display Pixel Sizes

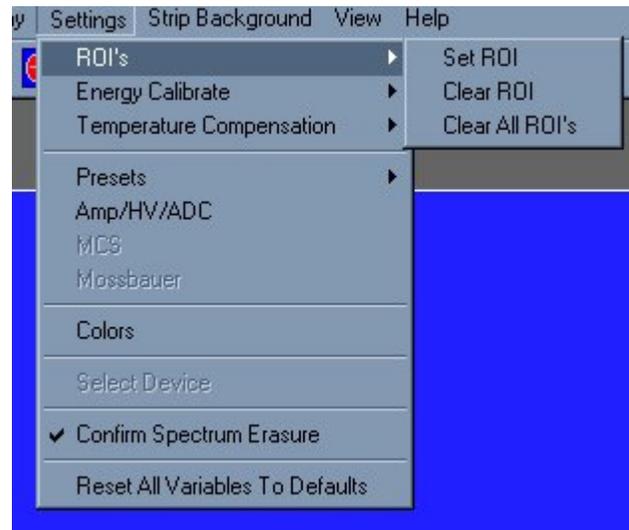


Allows the user to choose between 1, 2, and 3 pixels per data point displayed. The default is 2.

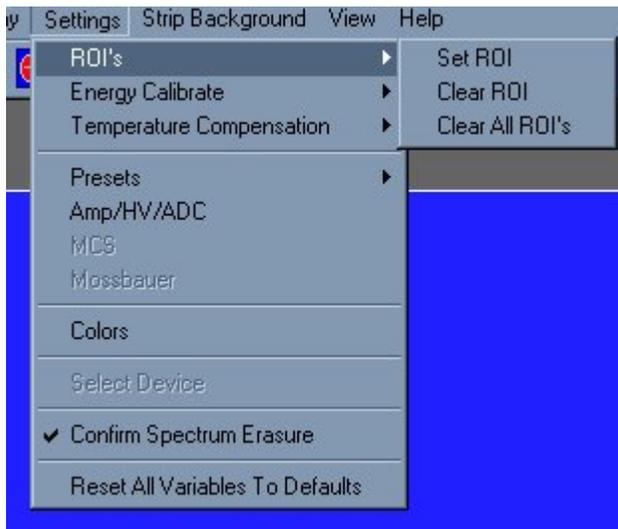
## Settings



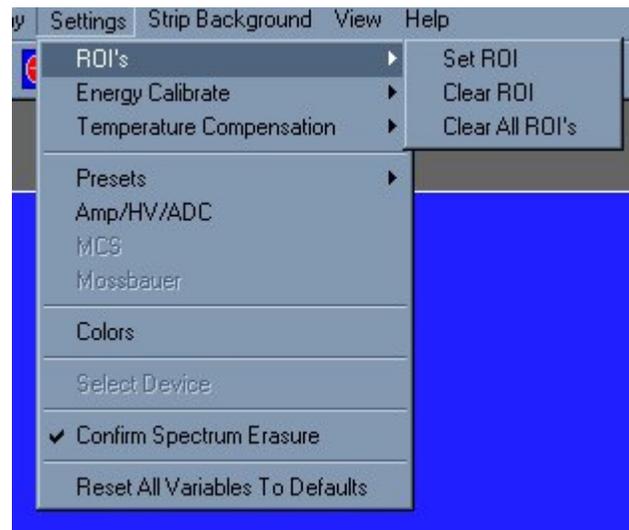
## Clear ROI



## Settings ROI's



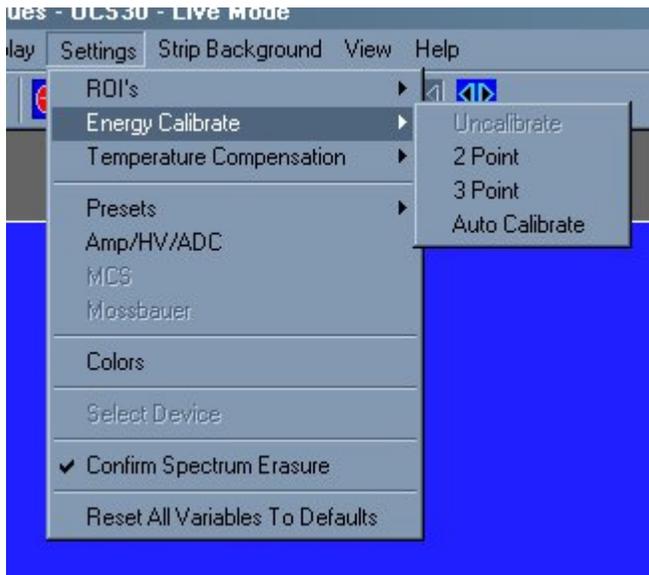
Clicking on **Clear ROI** will clear the ROI indicated by the marker.



Allows the user to select the option to set or clear an ROI.

Clicking on **Set ROI** allows the user to set the ROI.

## Settings Energy Calibrate



Opens a submenu for calibrating and uncalibrating the spectrum.

## Settings Energy Uncalibrate

Clicking **Energy Uncalibrate** will undo energy calibration and return the spectrum to the channel mode of data display.

## Settings Energy Calibrate 2 Point

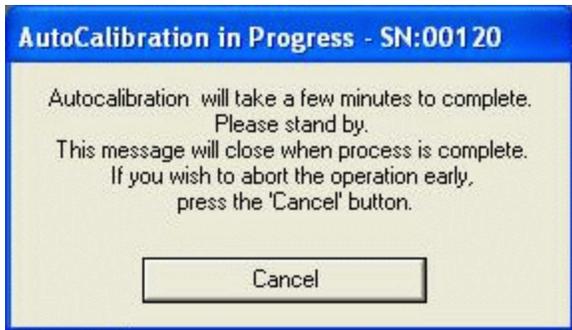
Clicking **2-Point** allows the user to calibrate the data using two points.

## Settings Energy Calibrate 3 Point

Clicking **3-Point** allows the user to calibrate the data using three points.

## Settings Energy Auto Calibrate

Clicking **Auto Calibrate** initiates a calibration sequence. During Auto Calibration, high voltage and gain settings are automatically adjusted in sequence to determine optimum settings for energy calibration assuming detection of Cs-137 source. Once started, the operator is given an opportunity to cancel. A cancelled autocalibration does not revert to prior settings.



## Settings Preset

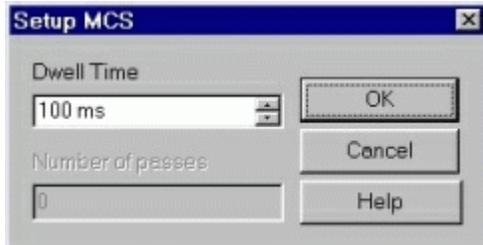
Clicking **Presets** allows the user to select the Presets Dialog box.

## Settings Amp/HV/ADC

Clicking **Amp/HV/ADC** allows the user to select the Amp/HV/ADC Dialog box.

## Settings MCS

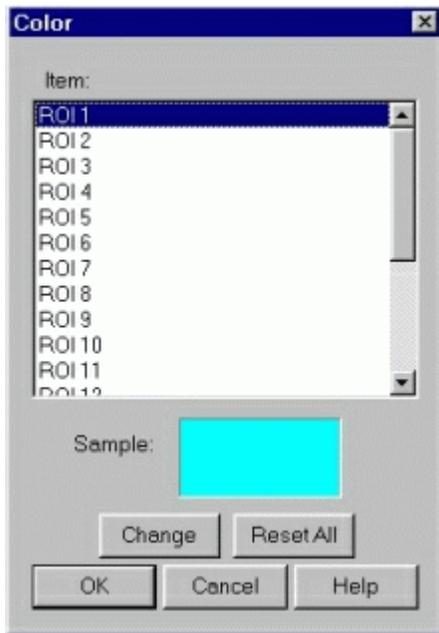
Clicking **MCS** allows the user to access the MCS Dwell Time dialog box, if the Mode is set to MCS.



Scroll to the desired Dwell Time then highlight the value selected then press OK.

## Settings Color

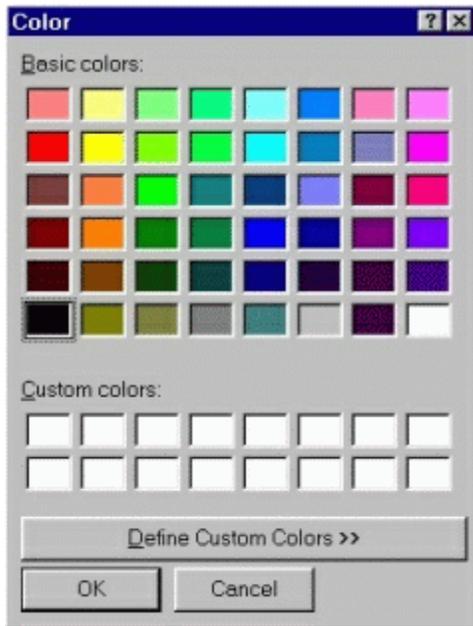
Clicking **Color** allows the user to select the **Colors Dialog Box** to set or change the colors for the ROIs and Background .



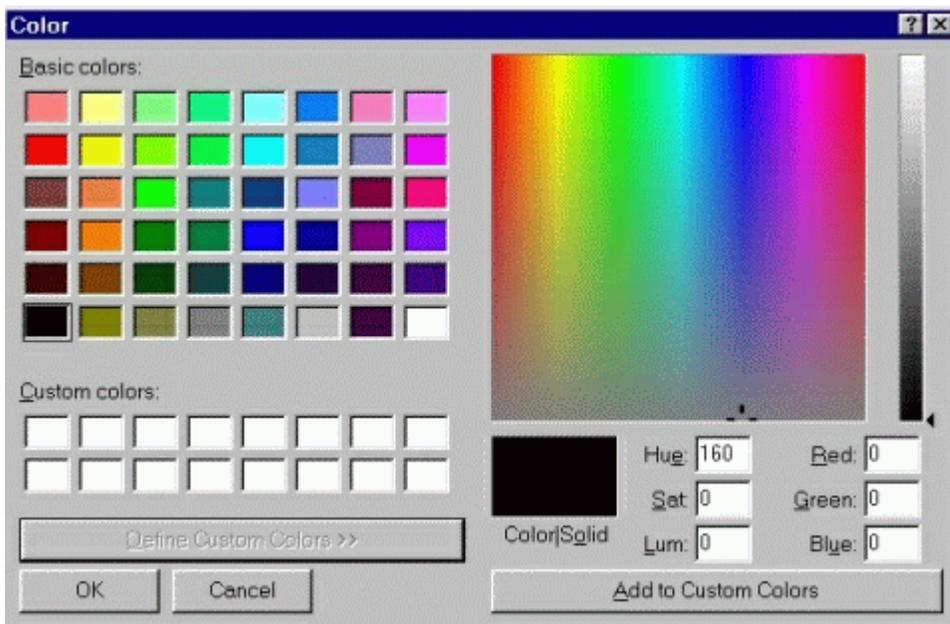
The **Color Dialog Box** allows the user to select custom colors for ROIs, Plot Background, Plot Border and Text.

Select the item to change, click on **Change**, select the desire color, click on **OK**, returns to the **Color** screen, make additional color changes, when all color changes have been made, click on **OK**, enters data and returns to spectrum screen.

**Color** allows the user to select a range of **Basic Colors** or create **Custom Colors**.



Dialog Box with standard Colors.



Dialog Box expanded for custom colors.

**Note:**

Setup of computer graphic may affect the true color of the color selected.

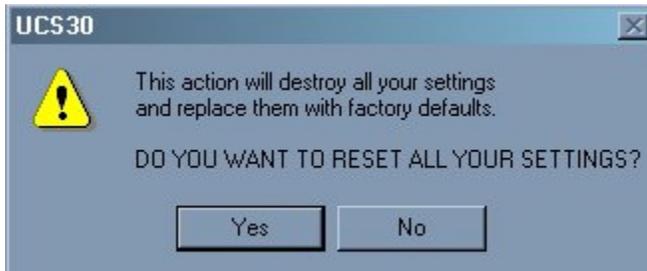
**Settings Confirm Spectrum Erasure**

Unchecking **Confirm Spectrum Erasure** allows the user to bypass the confirmation of erasing current spectrum data. By default, this option is checked each time the application is started. If

the setting is unchecked, erasure of the current spectrum is immediate and cannot be undone--use this feature wisely. When the setting is checked, a request to erase is followed by the display of a confirmation dialog box to give an opportunity to cancel the request.

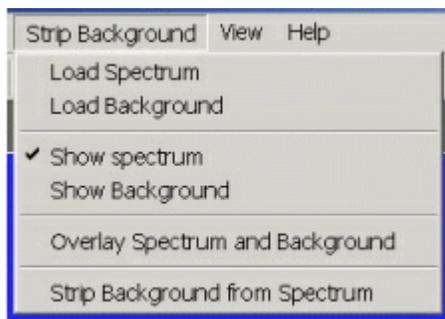
### Settings Reset All Variables To Defaults

Clicking **Reset All Variables To Defaults** results in configuration settings being reset to the initialized state.



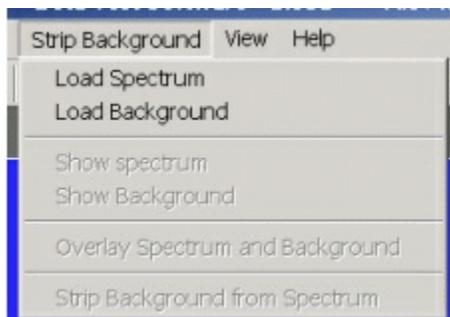
A confirmation dialog box will be presented to give an opportunity to cancel the request. Once accepted, the changes are made and cannot be undone. Click on 'Yes' to reset defaults, or on 'No' to cancel the operation.

### Strip Background



Allows the user to load a spectrum and a background and then strip the background from the spectrum.

### Strip Background

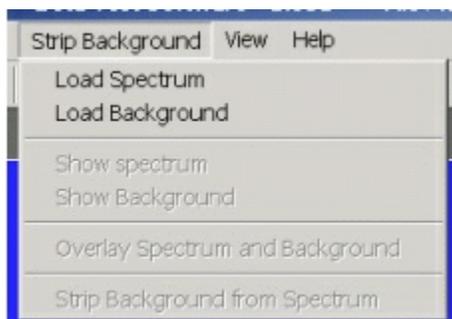


The Strip Background option is available only in the File Mode. The user may load two files (Spectrum and Background) and subtract the second file from the first. The portion subtracted is based on a time adjustment to the data in the second file. For example if the first file was measured with 100 seconds live time and the second file was measured with 200 seconds live time, then the data in the second file is divided by 2 (200 seconds / 100 seconds) before it is subtracted.

### Background Subtraction

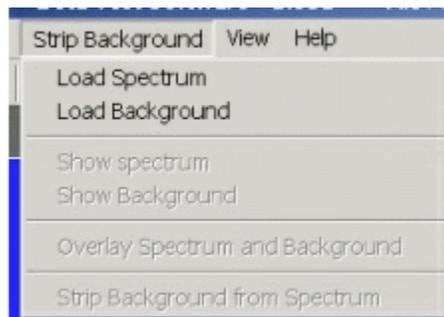
This is a special case of spectrum stripping. Collect a background sample spectrum, usually for a long collection time. Load this spectrum as Background and click on 'Strip Background from Spectrum.' The live time fraction of the background is subtracted from spectrum. This provides a convenient method of removing naturally occurring background from a sample spectrum and can be very useful when working with low level environmental samples.

### Load Spectrum



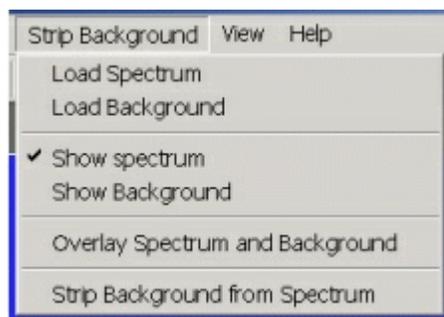
Click on **Load Spectrum** and in the **File Dialog Box** that opens, select the spectrum you intend to have the background stripped from. For example, the spectrum may be taken for an isotope, the background may be the readings with no isotope present.

### Load Background



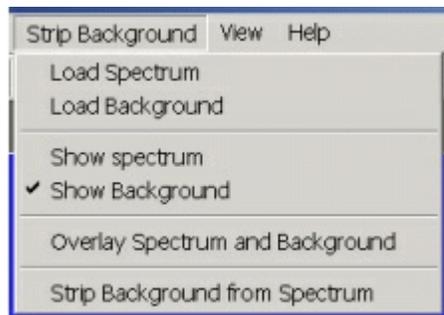
Click on **Load background** and in the **File Dialog Box** that opens, select the background you intend to strip from the first. For example, the spectrum may be taken for an isotope, the background may be readings with no isotope present.

### Show Spectrum



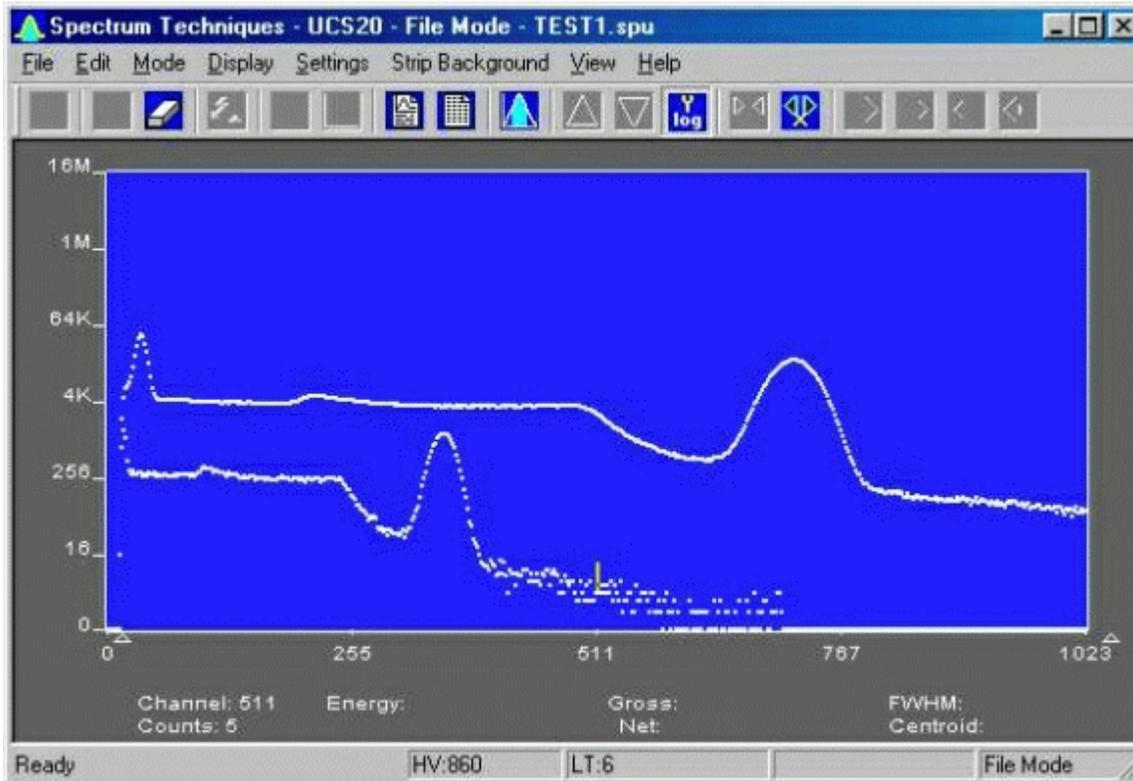
Click **Show Spectrum** to view spectrum.

### Show Background



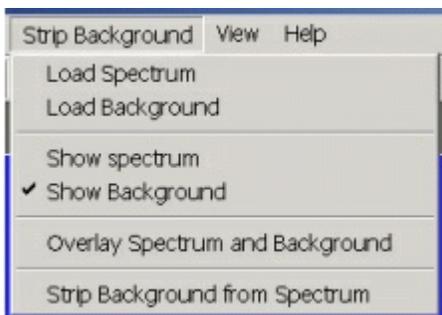
Click **Show Background** to view background.

## Overlay Spectra



Click **Overlay Spectra** to view the spectrum and the background at the same time.

## Strip Background from Spectrum



Click **Strip Background from Spectrum** to subtract the two spectra, where the background is corrected for the difference in the data collection time to give a correct proportion. As an example, if the background count time is 10 minutes and the sample count time is 60 minutes, then the **Strip Background from Spectrum** function will subtract  $1/6$  (10 minutes background count time/60 minutes sample count time) of the background counts from the sample spectrum.

## View



Allows the user to display or not display the Tool Bar and/or the Status Bar.

## Tool Bar

Allows the user to display or not display the Tool Bar.

## Status Bar

Allows the user to display or not display the Status Bar.

## Help



The **Help** menu provides a convenient operator reference for the UCS-30 in the standard Windows Help format.

## Contents

The **Help** menu provides a convenient operator reference for the UCS-30 in the standard Windows Help format.

## Using Help

The **Using Help** item provides the standard Windows Help on using the Windows Help system.

## About

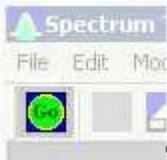
Displays a splash screen with the Application name and version number.



## Tool Bar



## Go



**Go** allows the user to start the acquire mode of a spectrum. This can also be accomplished by clicking on the green **Start Icon** on the display screen. Optionally, pressing 'A' while pressing and holding 'Ctrl' and 'Shift' keys will start acquisition.

## Stop



**Stop** allows the user to stop the acquire mode of a spectrum. This can also be accomplished by clicking on the red **Stop Icon** on the display. Optionally, pressing 'S' while pressing and holding the 'Ctrl' and 'Shift' keys will stop acquisition.

## Erase



**Erase** allows the user to erase the spectrum when in stop mode. This can also be accomplished by clicking on the **Eraser Icon** on the display screen. Optionally, pressing 'E' while pressing and holding the 'Ctrl' and 'Shift' keys will initiate an erase request.

Caution: If **Settings-Confirm Spectrum Erasure** is unchecked, erasure is immediate and final.

## Show Peak Report



If regions of interest, ROIs, have been set around peaks in a spectrum, the **Peak Report** provides a convenient method of displaying peak information in tabular form. Readout will be in energy units if the energy calibration is active.

## Show Data Report



**Data Report** includes all hardware setting, counting parameters and spectrum data. ROI data is reported by lower and upper channels set, gross, net, FWHM, centroid, all channels and corresponding counts.

## Amp/HV/ADC



Allows the user to select the **Amp/HV/ADC** Dialog box.

## Presets



Allows the user to select the **Presets** Dialog box.

## ROI



Allows the user to set an ROI.

## Spectrum Window Sizing



These buttons allow the user to set the size of the X and Y axes.

If a button is grayed, its function is not available for use. Scroll bars will appear when a spectrum is zoomed in or when it is being viewed in linear mode to provide further control.

## Y axis Log



Clicking the Y axis Log button sets the Y axis to a logarithmic scale with a maximum range of 16 million counts.

## X axis expand



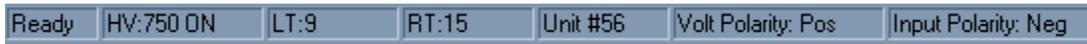
Clicking the X axis expand button increases the span of the X axis, up to the maximum set by the Conversion Gain.

## X axis contract



Clicking the X axis contract button decreases the span of the X axis.

## Status Bar



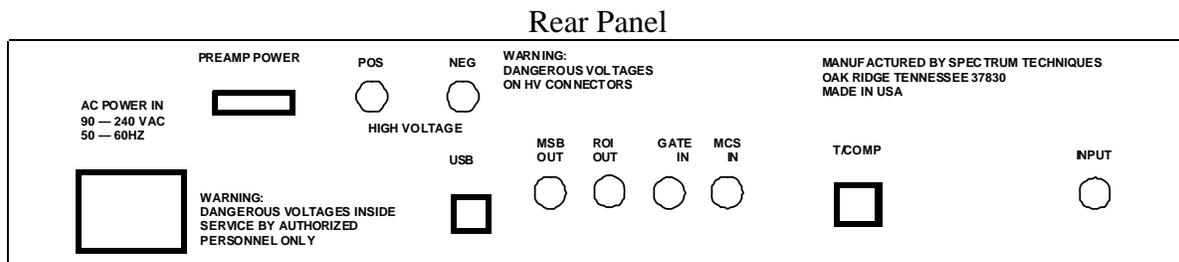
The status bar at the bottom of the window displays a context sensitive help message on the left side, the high voltage, live time, real time, the selected device, high voltage and input polarities on the right side.

# Specifications

## Hardware

- Physical:** Single instrument includes preamplifier, amplifier, detector high voltage, 4096-channel (maximum) multichannel analyzer with data memory, LLD and ULD. Fully compatible with many scintillation detectors and commercial tube bases.
- Amplifier:** On-board combination preamplifier/amplifier for use with scintillation detectors and PMTs. Computer controlled coarse and fine gain from x1 to x160.
- ADC:** Wilkinson type with 80 MHz clock and computer selected conversion gain of 4096, 2048, 1024, 512, or 256 channels. Direct input accepts pulse peaking times of 1  $\mu$ sec. to 10  $\mu$ sec. Includes dead-time correction when used in Live-time mode.
- LLD & ULD:** **Lower Level- and Upper Level-discriminators.** Independently computer controlled in 4-channel increments over entire input range. Operates prior to ADC for reduced system dead time.
- Modes:** MCA for pulse height analysis, or MCS for half-life decay or other time related studies.
- Timers:** Real-time or Live-time operation selectable in 1-second increments for PHA, or dwell times from 10 msec. to 600 seconds per channel in MCS mode.
- Data Memory:** On-board static RAM, 4096 channel (x) 3 Bytes for data, plus region-of-interest flag.
- Deadtime:** System dead-time is computed and displayed on screen during acquisition.
- Power:** AC line powered with an auto sensing power supply for 100 – 250 VAC, 10 watts total.

## Connections On Rear Panel:



## Software

- System:** Operates under Windows® 2000, Windows® XP with 600 kb disk space for the executable file and 6 meg for the optional help file available disk space, 64 MB RAM (128 MB recommended), and compatible mouse.
- Display:** VGA or SVGA color graphics (800x600 recommended. Linear vertical scale adjusts from 64 to 16M and full range logarithmic display. Horizontal 4096 channels with reduction down to 128 channels.
- Time Mode:** Preset live-time or preset real-time selection. Both times are recorded and displayed.
- ROIs:** Multiple Regions-of Interest using color coding.
- Integral:** When cursor is in ROI, computes gross area, net area with end point averaging, centroid and FWHM.
- Energy Cal:** 2-point linear or 3-point quadratic converts cursor position reading directly to energy units. (Time units in MCS mode.)
- Temp Comp:** Temperature compensation adjusts high voltage to compensate for fluctuations in temperature, when using a suitable PMT base.
- Strip:** Subtracts channel-by-channel time normalized data stored in File Mode. Overlays two saved spectra in File Mode
- Smooth:** 3-point smoothing of selected displayed data.
- Control:** Software control of High Voltage, Amplifier Gain, Lower and Upper level discriminators, and ADC Conversion Gain.
- File:** Save or load data file and header information in binary or spreadsheet compatible formats.
- Print:** Prints current screen display to Windows printer.
- ROI File:** Saves ROI data, centroid, FWHM, gross and net integrals, and header information in spreadsheet compatible format.
- IsoMatch:** Isotope library text file with peak markers and labeling for overlaying on spectrum for quick isotope identification. Library may be edited from Edit, IsoMatch pull down menu.

## Spectrum Techniques Contact

### ***SPECTRUM TECHNIQUES, LLC.***

106 Union Valley Road  
Oak Ridge, TN 37830  
USA.

Tel. (865) 482-9937 Fax. (865) 483-0473

e-mail. [sales@SpectrumTechniques.com](mailto:sales@SpectrumTechniques.com)

Web Site. <http://www.SpectrumTechniques.com>

## Time-to-Amplitude Converter/SCA

The EG&G ORTEC Model 567 Time-to-Amplitude Converter/Single-Channel Analyzer (TAC/SCA), measures the time interval between start and stop input pulses, generates an analog output pulse proportional to the measured time, and provides built-in single-channel analysis of the analog signal. Additional gating modules are not necessary with this unit, and timing experiments requiring time ranges of 10 ns to 2 ms may be performed with single-channel analysis, giving the experimenter unparalleled flexibility in analyzing random nuclear events that occur within a selected time range. Time ranges from 50 ns to 2 ms are provided via the front-panel controls.

Separate gating (anticoincidence or coincidence) of the start and stop inputs eliminates unwanted events from the time spectra via externally imposed energy or timing restrictions. The Model 567 also incorporates a built-in SCA inhibit feature in which a TAC output is available only if the output pulse falls within the window restrictions imposed by the SCA. This feature may be switched in or out by a convenient front-panel switch.

In addition to its start and stop input gating capabilities, the Model 567 provides for a pulsed or dc-level Reset/Inhibit signal via a front-panel input connector. A Reset/Inhibit input signal terminates the conversion cycle and maintains a reset condition, inhibiting further TAC conversions for the duration of the Reset/Inhibit pulse. A TAC output pulse that is in process at the time a Reset/Inhibit input is received will be completed before converter reset is initiated.

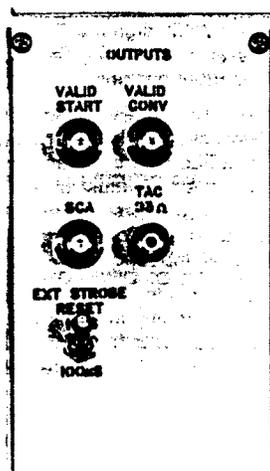
Valid Start and Valid Conversion outputs are provided for each accepted start and stop input respectively. The duration of the Valid Start output indicates the interval from the accepted start until the end of reset. Valid Conversion occurs from the end of the

internal delay after stop to the end of reset.

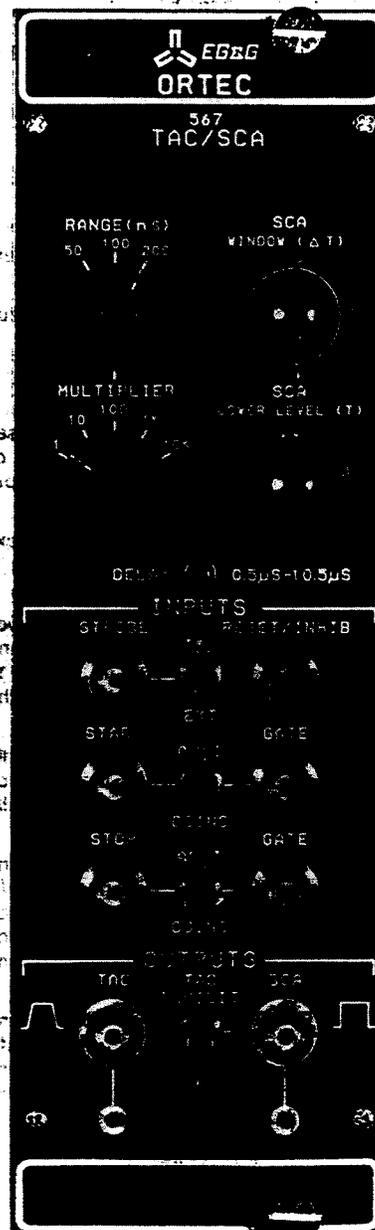
The selectable TAC output width and variable delay, which are easily adjustable, further serve to make the Model 567 a flexible instrument. The output of the TAC may be synchronized with the stop signal or an external strobe signal to further enhance its versatility.

The single-channel analyzer section of the Model 567 allows the experimenter to place very specific time restrictions on the timing spectrum. The SCA is operated in the Window position, where the upper-level discriminator setting is added to that of the lower-level discriminator. The SCA output pulse width is equal to the time from the occurrence of the TAC output until the end of the reset pulse or the end of the TAC output. The synchronization of the SCA output with the stop input virtually eliminates any time walk in the SCA output.

All Model 567 inputs are printed wiring board (PWB) jumper-selectable to accept either negative or positive NIM-standard signals. All inputs and outputs are dc-coupled so that changing input count rates will not hinder normal operation of the Model 567. The TAC output should be connected to the dc-coupled input of a multichannel analyzer (MCA) for optimum high-count-rate performance.



- For time spectroscopy in the range from 10 ns to 2 ms
- Includes SCA to set a time window for coincidence experiments
- Valid Start and Valid Conversion outputs
- Selectable output delay and width
- Output synchronized with a stop or external strobe signal
- Provision to reject unwanted start or stop input signals
- Positive or negative input signals



## Specifications

### PERFORMANCE

#### Time-to-Amplitude Converter

**TIME RESOLUTION** FWHM  $\leq 0.01\%$  of full scale plus 5 ps for all ranges.

**TEMPERATURE INSTABILITY**  $\leq \pm 0.01\%/^{\circ}\text{C}$  ( $\pm 100$  ppm/ $^{\circ}\text{C}$ ) of full scale plus 10 ps/ $^{\circ}\text{C}$ , 0 to 50 $^{\circ}\text{C}$ .

**DIFFERENTIAL NONLINEARITY** Typically  $< 1\%$  from 10 ns or 2% of full scale (whichever is greater) to 100% of full scale.

**INTEGRAL NONLINEARITY**  $\leq \pm 0.1\%$  from 10 ns or 2% of full scale (whichever is greater) to 100% of full scale.

**RESET CYCLE** Fixed 1.0  $\mu\text{s}$  for X1 and X10 Multipliers, fixed 5  $\mu\text{s}$  for X100 Multiplier, and fixed 50  $\mu\text{s}$  for X1K and X10K Multipliers. Occurs after Over Range, Strobe cycle, or Ext Strobe Reset cycle.

**START-to-STOP CONVERSION TIME** Minimum  $\leq 5$  ns.

#### Single-Channel Analyzer

**THRESHOLD INSTABILITY**  $\leq \pm 0.01\%/^{\circ}\text{C}$  ( $\pm 100$  ppm/ $^{\circ}\text{C}$ ) of full scale, 0 to 50 $^{\circ}\text{C}$  (referenced to +12 V NIM bin).

**THRESHOLD NONLINEARITY**  $\leq \pm 0.5\%$  of full scale.

### CONTROLS (Front Panel)

**RANGE (ns)** Three-position rotary switch selects full scale time interval of 50, 100, or 200 ns between accepted Start and Stop input signals.

**MULTIPLIER** Five-position rotary switch extends time range by a multiplying factor of 1, 10, 100, 1K, or 10K.

**DELAY** 20-turn screwdriver-adjustable potentiometer varies the delay of the TAC and SCA outputs from 0.5  $\mu\text{s}$  to 10.5  $\mu\text{s}$ , relative to an accepted Stop input signal; operable in the Int Strobe mode only.

**STROBE MODE** Two-position locking toggle switch selects either Internal or External source for initiating the strobe cycle to strobe valid information from the TAC and SCA outputs.

**START GATE MODE** Two-position locking toggle switch selects Coincidence or Anticoincidence mode of operation for the Start circuitry. Start circuitry is enabled in the Coinc position or inhibited in the Anti position during the interval of a Start Gate input signal.

**STOP GATE MODE** Two-position locking toggle switch selects Coincidence or Anticoincidence mode of operation for the Stop circuitry. Stop circuitry is enabled in the Coinc position or inhibited in the Anti position during the interval of a Stop Gate input signal.

**SCA WINDOW ( $\Delta T$ )** 10-turn precision locking potentiometer sets the SCA upper-level discriminator threshold from 0.05 V to 10.05 V above the Lower Level (T) setting.

**SCA LOWER LEVEL (T)** 10-turn precision locking potentiometer sets the SCA lower-level discriminator threshold from 0.05 V to 10.05 V.

**TAC INHIBIT** Two-position locking toggle switch. In the Inhibit position, the TAC output is available only if the output amplitude is within the SCA window. In the Out position, the SCA has no effect on the TAC output.

### CONTROLS (Rear Panel)

**EXT STROBE RESET** Two-position locking toggle switch allows the converter to be reset nominally 10  $\mu\text{s}$  or 100  $\mu\text{s}$  after an accepted Stop input signal if an Ext Strobe signal has not been received.

### INPUTS

All six front-panel inputs listed below are dc-coupled, edge-triggered, and printed wiring board (PWB) jumper selectable to accept either negative or positive NIM-standard signals. Input impedance is 50  $\Omega$  in the negative position and  $> 1\text{K}$  in the positive position. The threshold is nominally -400 mV in the negative position and +2 V in the positive position.

**STROBE** Provides an external means to strobe a valid output signal from the TAC in the Ext Strobe mode. The input signal, exceeding threshold within the Ext Strobe Reset interval after the Stop input, initiates the read cycle for the linear gate to the TAC output. Factory-set in the positive input position. Ext Strobe Reset interval has a minimum value of  $\sim 0.5$   $\mu\text{s}$  and a maximum value of nominally 10  $\mu\text{s}$  or 100  $\mu\text{s}$ , switch-selectable on rear panel.

**START** Time conversion initiated when Start input signal exceeds threshold. Factory-set in negative input position.

**STOP** Time conversion terminated when Stop input signal exceeds threshold. Factory-set in negative input position.

**RESET/INHIB** Terminates conversion cycle and maintains reset condition, inhibiting further TAC conversions, for the duration of the reset cycle or the Reset/Inhib pulse, whichever is longer. A TAC output pulse in process at the time of a Reset/Inhib signal will be completed before converter reset is initiated. Factory-set in the positive input position.

**START GATE** Provides an external means of gating the Start circuitry in either Coincidence or Anticoincidence with the Start input signal. Start Gate input signal must cross threshold  $\geq 10$  ns prior to the Start input signal and overlap the trigger edge of the signal. Factory-set in the positive input position.

**STOP GATE** Provides an external means of gating the Stop circuitry in either Coincidence or Anticoincidence with the Stop input signal. Stop Gate input signal must cross threshold  $\geq 10$  ns prior to the Stop input signal and overlap the trigger edge of the signal. Factory-set in the positive input position.

### OUTPUTS

**TAC** Front- and rear-panel BNC connectors provide unipolar pulse.

**Amplitude** 0 to +10 V proportional to Start/Stop input time difference.

**Time** End of delay period in Int Strobe mode; prompt with Strobe input in Ext Strobe mode.

**Width** Adjustable by PWB potentiometer from 1  $\mu\text{s}$  to 3  $\mu\text{s}$ .

**Impedance** Front panel  $Z_0 < 10 \Omega$ ; rear panel 93  $\Omega$ .

**Rise Time**  $\sim 250$  ns.

**Fall Time**  $\sim 250$  ns.

**VALID START** Rear-panel BNC connector provides NIM-standard slow positive logic level signal.

**Amplitude** Nominally +5 V. Complement signal selectable by PWB jumper.

**Time and Width** From accepted Start input to end of reset.

**Impedance**  $Z_0 < 10 \Omega$ .

**Rise Time**  $\leq 50$  ns.

**Fall Time**  $\leq 50$  ns.

**VALID CONV** Rear-panel BNC connector provides NIM-standard slow positive logic level signal to indicate a Valid Conversion.

**Amplitude** Nominally +5 V. Complement signal selectable by PWB jumper.

**Time and Width** From end of internal delay after Stop to end of reset.

**Impedance**  $Z_0 \leq 10 \Omega$ .

**Rise Time**  $\leq 50$  ns.

**Fall Time**  $\leq 50$  ns.

**SCA** Front- and rear-panel connectors provide NIM-standard slow positive logic level signals.

**Amplitude** Nominally +5 V. Complement signal selectable by PWB jumper.

**Time and Width** From start of TAC linear output to either end of reset or end of linear output. PWB selectable. Factory-set at end of reset.

**Impedance**  $Z_0 \leq 10 \Omega$ .

**Rise Time**  $\leq 50$  ns.

**Fall Time**  $\leq 50$  ns.

### ELECTRICAL AND MECHANICAL

**POWER REQUIRED** +24 V, 95 mA; +12 V, 210 mA; -24 V, 165 mA; -12 V, 330 mA.

#### WEIGHT

Net 1.4 kg (3 lb).

Shipping 3.2 kg (7 lb).

**DIMENSIONS** NIM-standard double-wide module 6.90  $\times$  22.13 cm (2.70  $\times$  8.714 in.) per TID-20893 (Rev).

### Ordering Information

To order, specify:

Model	Description
567	Time-to-Amplitude Converter/SCA

# Phillips Scientific

## Octal Discriminator

### NIM MODEL 705

### FEATURES

- INDIVIDUAL THRESHOLD AND WIDTH CONTROLS
- LINEAR SUMMED OUTPUT
- BOTH FAST VETO AND BIN GATE
- LOW COST
- EIGHT (8) CHANNELS IN A SINGLE WIDTH NIM MODULE

### DESCRIPTION

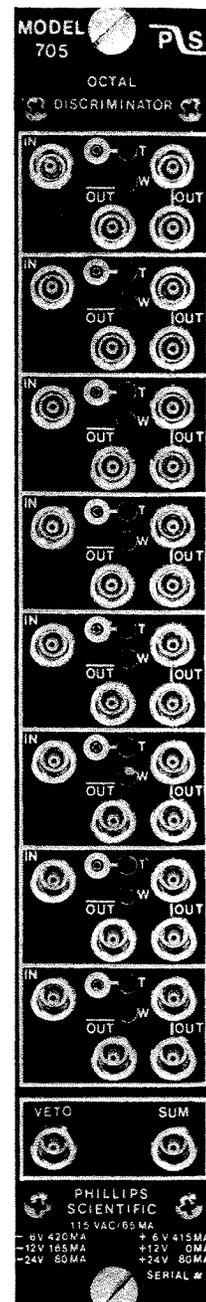
The Model 705 was specifically designed for modern experiments with large counter arrays, offering high performance and reliability at a reasonable cost. The 705 features eight (8) totally independent channels with individual threshold and width controls. In addition, a fast veto input and a summed output are common to all channels.

Each channel has a threshold adjustment continuously variable from  $-10\text{ mV}$  to  $-1\text{ Volt}$  with a front panel test point providing a DC voltage ten (10) times the actual threshold setting. Likewise, each channel has a non-updating regeneration circuit for adjustable output widths from  $6\text{ nSEC}$  to  $150\text{ nSEC}$ .

A unique summed output is common to all eight channels providing  $-1\text{ mA}$  of current for each activated channel, thus allowing a fast decision to be made on the number of channels simultaneously hit. Up to 16 channels can be "OR'D" directly by cable to other summed outputs allowing a versatile scheme to form a trigger.

A fast veto input allows simultaneous inhibiting of all channels to reject unwanted events early in the system. Similarly, a bin gate will inhibit the entire module when applied via the rear connector.

The outputs are the current source type with one pair of negative bridged outputs and one complement for each channel. When only one output of the bridged pair is used, a double-amplitude NIM pulse ( $-32\text{mA}$ ) is generated, when both connectors are used normal NIM levels ( $-16\text{mA}$ ) are produced. The outputs have crisp, clean transitions, and their shapes are unaffected by the loading conditions of the other outputs.



Phillips Scientific

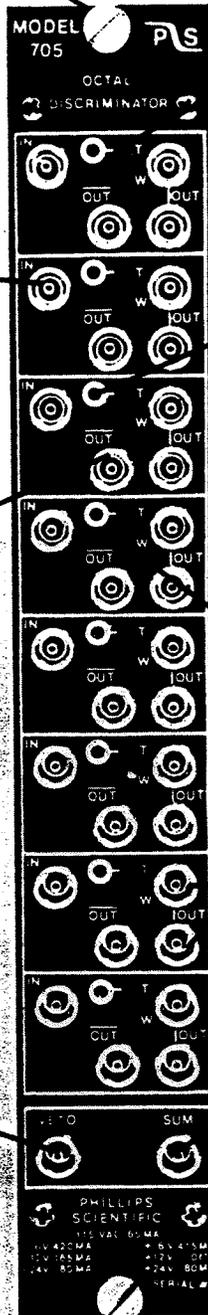
A THEORY DEVELOPMENT COMPANY  
150 Hilltop Road • Ramsey, NJ 07446 • (201) 934-8015 • Fax (201) 934-8269



MODEL 705 OCTAL DISCRIMINATOR

(FRONT PANEL DESCRIPTION)

Standard #1 NIM Packaging  
in accordance with  
TID-20893



Threshold Control; 15-turn  
Screwdriver Adjustment,  
Variable from -25 mV  
to -1 Volt

50 Ohm Input

Threshold Monitor; Test  
Point provides a DC  
Voltage 10 times the  
actual Threshold Setting  
(-250 mV to -10 V)

One Complemented NIM Output.  
Quiescently -16 mA (-800 mV)  
Goes to 0 mA (0 Volts) during  
output.

Output Width Control;  
15-turn Screwdriver  
Adjustment, Variable from  
6 nSec to 150 nSec.

Double amplitude bridged  
output; -32 mA (-1.6 Volts  
across 50 ohms, -.8 Volt  
with two 50 ohm terminations)

Fast Inhibit Input accepts  
normal NIM logic (-500 mV)  
50 Ohm Impedance

Linear summed output;  
-1 mA/step. (-50 mV across  
50 ohms)

**NOTE:** Bin Gate Enable/  
Disable Switch on Rear  
Panel permits Inhibiting  
via Bin Connector.

Voltage and Current  
Requirements

**Phillips Scientific**

13 Ackerman Avenue • Suffern, New York 10901 • USA • (914) 357-9417

# Phillips Scientific

## Logic Unit

# NIM MODEL 755

### FEATURES

- VERSATILE LOGIC MODULE WITH MAJORITY LEVEL SELECTION
- FOUR INDEPENDENT CHANNELS
- 125 MHz RATE CAPABILITY
- DEADTIMELESS UPDATING OUTPUTS
- FAST ANTI-COINCIDENCE CAPABILITY

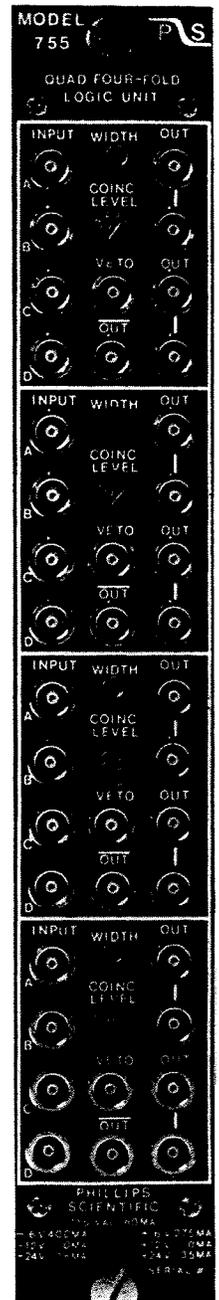
### DESCRIPTION

The model 755 logic unit contains four channels of four input logic with veto in a single width NIM module. Logic AND, OR majority logic, fan-in/fan-out, and anti-coincidence functions can be performed with this versatile module. All functions are direct coupled and operate to over 125 MHz with input overlap times as narrow as 1 nSEC.

Each channel has four logic inputs, an anti-coincidence input, a coincidence level switch, and five outputs with common width control. The inputs are enabled by connecting the input cable to the desired input, eliminating errors often occurring with switched inputs. The setting of the coincidence level switch then determines whether a logic OR, AND, or majority logic function will produce an output.

After the inputs have satisfied the logic function desired, triggering of an updating regenerative stage produces a standardized output pulse, variable from 4 nSEC to 1 uSEC, independent of the input pulse shapes or overlap times. The updating feature ensures deadtimeless operation, while the double-pulse resolution is 7.5 nSEC for fast counting applications.

The outputs are the current source type with two pairs of negative bridged outputs and one complement for each channel. When only one output of a bridged pair is used, a double-amplitude NIM pulse (-32 mA) is generated for driving long cables with narrow pulse widths. The outputs have transition times of typically 1.0 nSEC, and their shapes are virtually unaffected by the loading conditions of the other outputs.



**Phillips Scientific**

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## INPUT CHARACTERISTICS

### A, B, C, D<sub>i</sub>

Four inputs per section, LEMO connectors; accepts NIM level logic signals (-500 mV); 50 ohm input impedance direct coupled; input reflections are less than  $\pm 5\%$  for a 1 nSEC rise-time. Inputs are protected against damage from  $\pm 50$  volt input transients. Inputs respond to a 1 nSEC or greater input width.

### Fast Veto:

One input per section, LEMO connector; accepts NIM level logic signal (-500 mV); 50 ohm input impedance, direct coupled; less than  $\pm 5\%$  input reflection for a 1 nSEC risetime, protected against damage  $\pm 50$  volt input transients. Requires a 3.5 nSEC minimum input width in time with the input pulse leading edge to inhibit.

### Bin Gate:

Rear-panel slide switch enables or disables the slow bin gate via the rear connector. Signal levels are in accordance with the TID-20893 standard.

## OUTPUT CHARACTERISTICS

### General:

Five outputs per section, two pairs of negative bridged and one complemented NIM. The two pairs of bridged outputs are quiescently 0 mA and -32 mA during output. (-1.6 V into 50 ohms or -.8 V into 25 ohms). The complemented output is quiescently -16 mA and 0 mA during output. Risetimes and falltimes are less than 1.5 nSEC, and the output pulse shapes are optimized when the bridged outputs are 50 ohm terminated.

### Width Control:

One control per section; 15-turn screwdriver adjustment. Outputs are continuously variable from 4 nSEC to 1 uSEC; better than 0.15%/°C.

### Updating Operation:

The output pulse will be extended if a new input pulse occurs while the output is active. This provides deadtimeless operation and 100% duty cycle can be achieved.

## GENERAL PERFORMANCE

### Functions:

Logic AND, OR, majority logic, and logic fan-in/fan-out. All functions have leading edge inhibit with standardized outputs.

### Rate:

150 MHz minimum, input to output. Typically 160 MHz.

### Double-Pulse Resolution:

Less than 6.5 nSEC; Typically 6 nSEC with output width set at minimum.

### Input to Output Delay:

Less than 8 nSEC.

### Multiple Pulsing:

One and only one output pulse regardless of input pulse amplitude or duration.

### Power Supply Requirements:

-6 V @ 400 mA	+6 V @ 250 mA
-12 V @ 165 mA	+12 V @ 0 mA
-24 V @ 60 mA	+24 V @ 35 mA

115 VAC @ 60 mA

**Note: All currents within NIM specifications limits allowing a full-powered bin to be operated without overloading.**

### Operating Temperature:

0°C to 70°C ambient.

### Packaging:

Standard single width NIM module in accordance with TID-20893 and Section 524.

### Options:

Call Phillips Scientific to find out about available options.

**Phillips Scientific**

ANALOGY DEVELOPMENT COMPANY  
150 Hilltop Road • Ramsey, NJ 07446 • (201) 934-8015 • Fax (201) 934-8265

MODEL 755 QUAD FOUR-FOLD MAJORITY LOGIC UNIT

(FRONT PANEL DESCRIPTION)

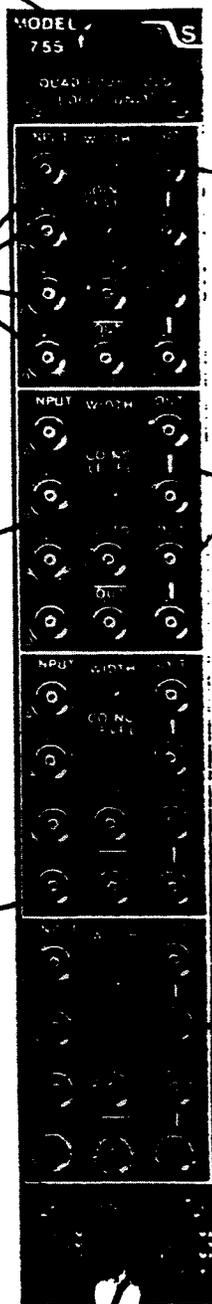
Standard #1 NIM Packaging  
in accordance with  
TID-20893

Four Logic Inputs; Accepts  
Normal NIM Logic (-500 mV)  
50 ohm Impedance

Four Position Coincidence  
Level Switch; Selects  
Logical "OR", "AND",  
or Majority Logic  
Functions.

One Complemented NIM  
Output. Quiescently  
-16 mA (-800 mV). Goes  
to 0 mA (0 Volts) during  
output.

NOTE: Bin Gate Enable/  
Disable Switch on Rear  
Panel permits Inhibiting  
via Bin Connector.



Output Width Control;  
15-turn Screwdriver  
Adjustment, Variable from  
4 nSec to 1  $\mu$ Sec.

Two pairs of bridged  
outputs; each pair delivers  
-32 mA (-1.6 Volts across  
50 ohms, -.8 Volt with  
both outputs 50 ohm  
terminated).

Fast Inhibit Input accepts  
normal NIM Logic (-500 mV)  
50 ohm Impedance

Voltage and Current  
Requirements

**Phillips Scientific**

13 Ackerman Avenue • Suffern, New York 10901 • USA • (914) 357-9417

## **LAB 3: 493L Experiment Development Laboratory**

**Paul R. Schwoebel**

**Special Note:** *This laboratory can only be taken after the student has completed Lab 1.*

### **Purpose**

Familiarize the student with all aspects involved in the development of an experiment.

### **Reading Assignment**

As needed: *Building Scientific Apparatus*, 3rd edition, by John Moore, Christopher Davis and Michael Coplan (Perseus Books, Cambridge MA, 2003). Other material as necessary for the particular experiment being developed.

### **Introduction**

An experimental scientist will develop scientific apparatus in order to conduct experimental studies. Even those planning on going into theoretical studies will find exposure to the development of scientific apparatus helpful because they will often interact collaboratively with experimental scientists.

### **Procedure**

The students will work with the assistance of the instructor and TA on the development of a new experiment for Senior Lab. The instructor will define the goal of the experiment and its basic arrangement. During their four week laboratory exercise the students will develop apparatus needed for the experiment. A given student group will have reasonable freedom in their activities that will involve: 1) Designing experimental apparatus, 2) Procuring the hardware/software needed to construct the apparatus, 3) Constructing the apparatus, and lastly, 4) Testing the apparatus and iterating on its design so as to achieve the measurements required.

Four weeks is not enough time to complete the development of an entire experiment for Senior Lab, and thus this will be a group effort over the course of the semester with one group handing off to another group until the experiment is complete.

The laboratory write-up necessary is to be in manual-type form describing the apparatus developed and how it is used. The write-up should provide sufficient information such that someone unfamiliar with the apparatus would be able to operate and repair the apparatus. For example the write-up should include mechanical drawings and/or electrical schematics of the components fabricated, photographs of the components, a description of their function, and an explanation of how they are used in the experiment.

# LAB 4: Double Slit Diffraction of Single Photons

Birk Reichenbach, Rob Cook, Devon Hjelm, and P. R. Schwoebel

## Introduction

The end goal of this experiment is to demonstrate, as Richard Feynman said, the *only* mystery that is at the heart of quantum mechanics. For our purposes, that mystery will be defined as, "If a single particle is incident upon some choice in path and it is impossible to determine which path the particle took, then there will be wave like interference between the possible paths. But however if there is in principle some way to determine which path was traveled than there will be no interference." The single particles here will be individual photons and the choice in path is Young's double slit. The issue is the wave-particle duality of light, which apparently propagates as a wave, but is detected as particles.

The quantum nature of this experiment is ensured by the fact that the photons will pass individually through the slit and therefore it is not in the classical limit of a large number of photons. Despite the fact that single photons pass through each slit one at a time, you will find that the photons still create a standard Young's double slit interference pattern. You should review the classical Young's double slit experiment and the results to compare with what you see here

The basic experimental approach is to attenuate a light source incident on a double slit to such a degree so as to insure single photons pass through each slit – that is without having one photon in each slit simultaneously. The spatial variation in the position at which these photons strike a plane behind the slits is then recorded, and the double slit interference pattern is reproduced. Besides simply arguing the single photon nature of the experiment from the degree of light source attenuation, you will also demonstrate the quantized nature of light experimentally by using coincidence techniques to show that there is not a photon in each slit at any given time.

## Apparatus

1. Light Source: The choice in light source was dictated by several requirements. First, a narrow enough frequency spectrum is needed such that the interference fringes will be easily resolved. Second, the wavelength of light needs to be easily detected with a reasonably high quantum efficiency. Lastly, as you will see, it is most straightforward to use a wavelength in the visible portion of the spectrum. One could use an incandescent light bulb (you might want to describe how this would be done after you have done this experiment) but the most straightforward approach is to use a laser. Our detector, discussed in the next section, will be a photomultiplier tube and for these the quantum efficiency increases as the photon wavelength decreases through the visible portion of the spectrum (why is this?). So the relatively inexpensive red HeNe laser is fine, but a green HeNe laser is even better. Your laser is a Coherent 31-2264-000 (serial No. 9726EF), a class IIIa laser with  $\lambda = 543.3\text{nm}$  and power of 0.3mW with a random polarization (specifications in the Appendix).

2. Light Tight Box: As this experiment is about measuring single photons, light present from other sources, or scattered light from the laser itself, can introduce significant errors. Hence the

experiment is set up in a light tight box (Length = 36", Width = 16", Depth = 9") see Fig. 1. As the PMTs dark current rises dramatically for 20 to 30 minutes following exposure to room light type intensities, both PMTs are enclosed in a secondary box as shown in Figure 1. This makes it possible to make certain changes to the apparatus without exposing the PMTs to room light. The box contains interlocks such that high voltage cannot be applied to the PMTs when either the  $10^5$  X attenuator (discussed below) is not in place, the box lid is not closed, or the inner PMT enclosure is not closed. In addition if not all of these conditions are met the electronic shutters on the inner PMT enclosure will not be open.

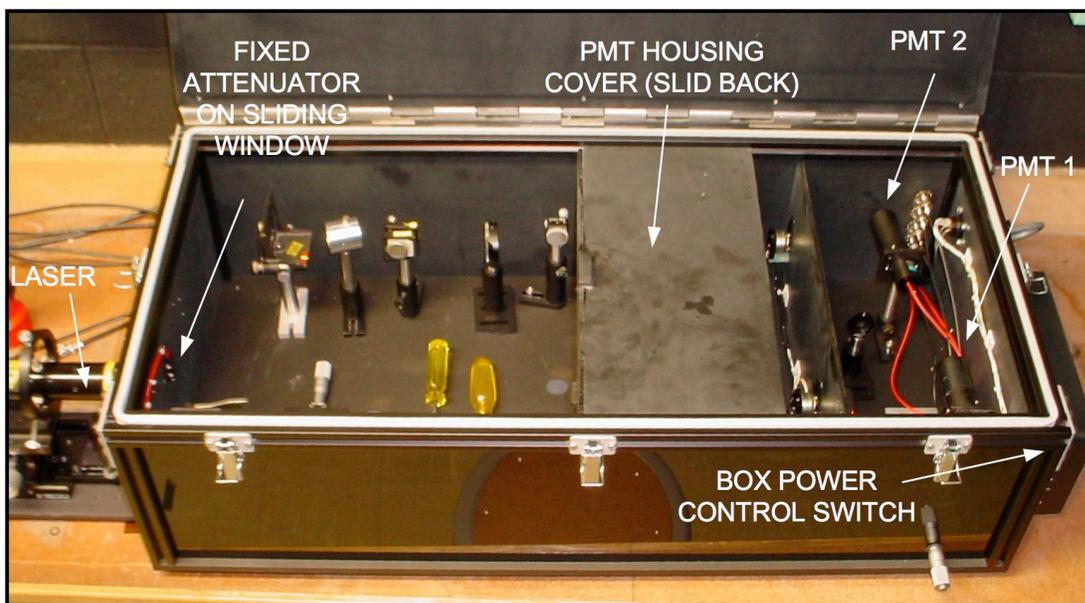


Figure 1. Photograph of the light tight box containing the experimental apparatus. A secondary light tight box encloses the 2 PMTs.

3. Photon Detector: The detectors used in this experiment are two Hamamatsu R1527 photomultiplier tubes (PMTs) (specifications in the Appendix). This photomultiplier was chosen its quantum efficiency at 543nm and its large signal to noise ratio. A high voltage source of LESS THAN -1200 V is applied to the PMTs. The size of the detector window on the PMT is a couple of centimeters in length however; the interference fringe measurement requires sub-millimeter spatial resolution. Therefore a single 50  $\mu$ m entrance slit (in a 1" fixed lens mount) is placed in front of PMT 1 and both are mounted on a translation stage. This provides the required spatial resolution as the detector and entrance slit can be translated across the interference pattern while measuring the photon flux. Both PMTs have been enclosed in a secondary light tight box and in a magnetic shield, thereby limiting their field of view to background and scattered photons.

The PMTs are extremely sensitive to light (they count single photons). Normal room light intensities or the full power of the laser will destroy the PMT if it is on. Hence, the PMT is never to be turned on without the attenuation in place and the lid of the box closed!

4. Light Source Attenuation: To decrease the power of the laser beam to a level such that not more than one photon passes through each slit at a time, there is a series of 1/2" neutral density filters (attenuators) available (one at  $10^1$  X, one at  $10^2$  X, and one at  $10^3$  X). Fixed to the outside of the light tight box on a sliding window is an attenuator of  $10^5$  X. This prevents exposure of the PMT to excessive light levels. This  $10^5$  X attenuation level may or may not be enough to ensure a diffraction pattern produced by one photon at a time. You should calculate the required attenuation level and implement that level using the additional attenuators provided as discussed below.

5. The Double Slits: There are three sets of double slits used in this lab. One set is a double slit from Lennox Lasers. Those slits are  $5.8 \mu\text{m}$  in width and separated by  $228 \mu\text{m}$ . You should calculate the expected fringe spacing as a function of distance for this double slit geometry. The second and third set have slits with a spacing of  $\sim 1\text{mm}$  in order to allow for integration of polarizers. One set of slits has no polarizers and the other set has polarizers installed behind each slit such that the light from one slit is polarized orthogonally to the light exiting the other slit.

### Experimental Procedure

Arrange the apparatus such that you can see the double slit interference pattern using the Lennox Laser slits by opening the window in the box to remove the  $10^5$  X attenuator. Align the pattern such that it falls on the entrance window to PMT 1. It will be useful to align an antinode over the entrance slit. The quantum nature of this experiment is insured by the fact that the photons pass individually through the slit and therefore that it is not in the classical limit of a large number of photons. Hence you must now determine the degree of laser light intensity attenuation required to reach the single photon limit. This determination is made by a time of flight argument using the speed of light, the dimensions of the flight path in the light tight box, and the laser power. Other considerations may involve the aperture effect of the double slits. Insert appropriate additional attenuation, if needed, using the attenuator holder and attenuators supplied.

Seal the boxes, close the window and apply high voltage to PMT 1. Observe its output on the oscilloscope. Adjust the gain of PMT 1 until your signals are roughly 30 mV or possibly greater. Using the discriminator and scaler count the number of photons you see in a given time interval. Scan the entrance slit/PMT assembly horizontally using the micrometer while recording the number of counts you see as a function of position. Is the Young's double slit interference pattern observed? Are the number of counts you measure in a given time at a given point what you expect to see? What sort of error appears in any spatial pattern observed?

To verify your experiment is in the single photon regime, it is interesting to now investigate obtaining a single photoelectron pulse height spectrum from the PMT. How many incident photons does it take to create one photoelectron?

PMTs employ multiple stages in order to achieve the gains necessary for the signal to be visible by other instruments. In the first stage, the photoelectron produced at the photocathode strikes the first dynode, which produces some number,  $\delta$ , of secondary electrons. These electrons then strike the second dynode, which in turn produces  $\delta^2$  electrons. This is repeated at each of the PMT's  $N$  dynodes so the final electron signal leaving the PMT is  $\delta^N$ . In general  $\delta$  increases as

some power ( $>1$ ) of the PMT voltage. There are statistical fluctuations in  $\delta$  and in the simplest case one may assume these to be described by the Poisson distribution with a mean value of  $\delta$  and a standard deviation of  $1/\delta^{1/2}$ .

What would the standard deviation be for 2 photoelectrons? What does this tell us about the distinguishing photon numbers as the number gets high? How would you expect  $\delta$  to affect the spacing between energy levels? What is the photon energy of the green laser light? How much energy is needed to produce a single photoelectron? Two photoelectrons?

For a single photoelectron, the output of the PMT should be an energy distribution with a peak. How would the PMT output appear if one *and* two photoelectron events were present in the PMT. Operating under conditions you used for producing the interference pattern with 'single' photons how does the output of the PMT appear if viewed using the MCA? Can you distinguish different peaks? If not try to increase or decrease the incident photon rate until you can see multiple peaks. Use this to calibrate your MCA. Which peak corresponds to what number of photoelectrons? of photons? Can you calculate  $\delta$  for a given PMT voltage? Did you indeed accumulate your interference pattern with one photon at a time?

With the correct arrangement above we showed the quantum effect of single photon interference. Assuming light actually appears as discrete quanta of light (photons), we insured there was only one in the box at a time however we did not actually show that these the light quanta passed through only one slit at a time. If each light quantum passed through both slits then we would not need quantum mechanics to explain the phenomenon.

To prove that the light passed through only one slit at a time we'll divert the light passing through one slit to PMT 1 and the light passing through the other slit to PMT 2. To do this use the polarizing double slit (you may want to look at the interference pattern produced by these slits using the unpolarizing slit assembly). Put the polarizing assembly in the light path such that the photon will first hit the double slit and then the polarizer. This way the polarizer has no way to influence the photons "decision" on how to pass the double slit. Use the fact that the beam is now polarized along with the mirror, polarizer, and glass slide supplied to guide the photons passing through each slit to the different PMTs as illustrated in Figure 2.

You may want to use a couple lenses to increase the diameter of the laser beam in order to better cover both slits of the double slit arrangement. How does one adjust the discriminator and coincidence to determine whether two photons pass through the two slits at the same time? Can one determine, on the average, how the time/distance separating the photons in the box from one another. If so, what distance do you estimate? What is the uncertainty in this measurement? Does

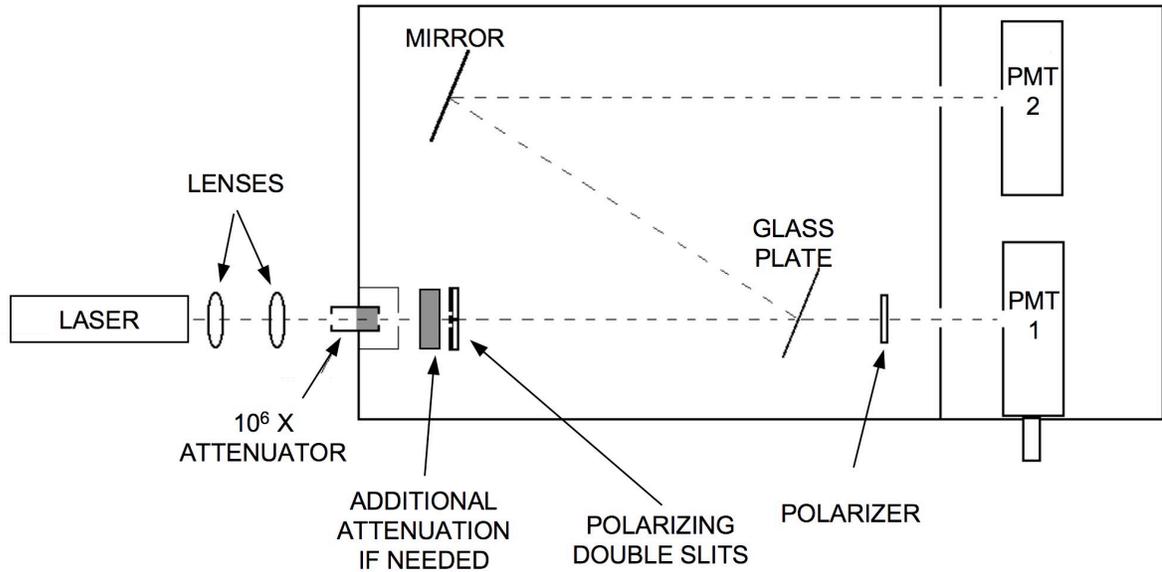


Figure 2. Schematic showing photon coincidence measurement

the number of photons you observe in each detector agree with what you would predict? Does the fact that these slits are different from the slits you used previously impact your conclusions? How?

**APPENDIX 1: Equipment Manuals**  
(Also refer to manuals associated with Experiment 2 on Nuclear Physics)

### High Cathode Sensitivity with Low Noise Photocathode

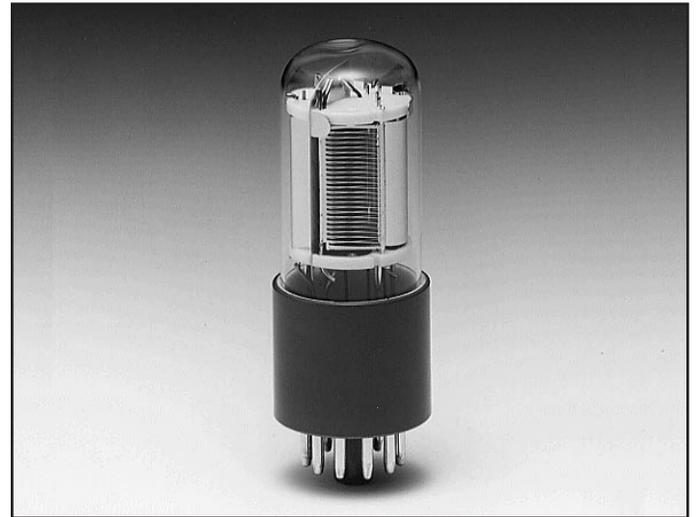
#### FEATURES

- Spectral Response ..... 185 to 680 nm
- Cathode Sensitivity
  - Luminous ..... 60  $\mu$  A/lm
  - Radiant at 400nm ..... 60 mA/W
- Anode Sensitivity (at 1000V)
  - Luminous ..... 400 A/lm
  - Radiant at 400nm .....  $4.0 \times 10^5$  A/W
- Low Dark Current ..... 0.1 nA
- Low Dark Counts (R1527P) ..... 10 cps

Hamamatsu R1527 features high cathode sensitivity, high current amplification, and low dark current.

Variant tube (R1527P) specially selected for photon counting application is also available.

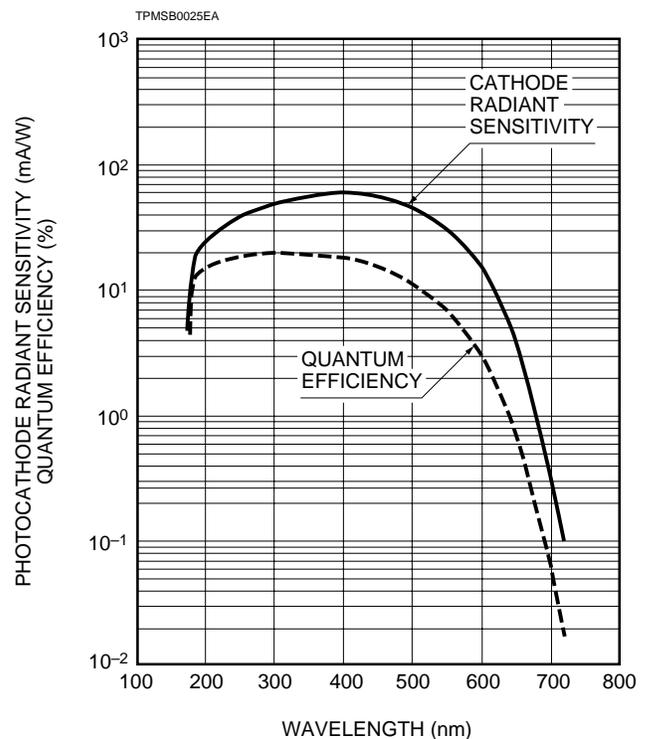
The R1527 is useful for fluorescence, chemiluminescence, Raman spectroscopy and low light level detection.



#### GENERAL

Parameter	Description/Value	Unit
Spectral Response	185 to 680	nm
Wavelength of Maximum Response	400	nm
Photocathode		
Material	Low noise bialkali	—
Minimum Effective Area	8 × 24	mm
Window Material	UV glass	—
Dynode		
Secondary Emitting Surface	Low noise bialkali	—
Structure	Circular-cage	—
Number of Stages	9	—
Direct Interelectrode Capacitances		
Anode to Last Dynode	4	pF
Anode to All Other Electrodes	6	pF
Base	11-pin base JEDEC No. B11-88	—
Weight	45	g
Suitable Socket	E678-11A (option)	—
Suitable Socket Assembly	E717-21 (option)	—

Figure 1: Typical Spectral Response



# PHOTOMULTIPLIER TUBES R1527, R1527P(For Photon Counting)

## MAXIMUM RATINGS (Absolute Maximum Values)

Parameter	Value	Unit
Supply Voltage		
Between Anode and Cathode	1250	Vdc
Between Anode and Last Dynode	250	Vdc
Average Anode Current	0.1	mA
Ambient Temperature	-80 to +50	°C

## CHARACTERISTICS (at 25°C)

Parameter	R1527 for General Purpose			R1527P for Photon Counting			Unit
	Min.	Typ.	Max.	Min.	Typ.	Max.	
Cathode Sensitivity							
Quantum Efficiency at 300nm (Peak)	—	19	—	—	19	—	%
Luminous <sup>B</sup>	40	60	—	40	60	—	μA/lm
Radiant at 400nm (Peak)	—	60	—	—	60	—	mA/W
Blue <sup>C</sup>	—	6.4	—	—	6.4	—	μA/lm-b
Anode Sensitivity							
Luminous <sup>D</sup>	200	400	—	200	400	—	A/lm
Radiant at 400nm	—	4.0 × 10 <sup>5</sup>	—	—	4.0 × 10 <sup>5</sup>	—	A/W
Gain <sup>E</sup>	—	6.7 × 10 <sup>6</sup>	—	—	6.7 × 10 <sup>6</sup>	—	
Anode Dark Current <sup>E</sup>							
After 30minute Storage in the darkness	—	0.1	2.0	—	0.1	0.5	nA
Anode Dark Counts <sup>F</sup>	—	—	—	—	10	50	cps
ENI(Equivalent Noise Input) <sup>G</sup>	—	3.7 × 10 <sup>-17</sup>	—	—	3.7 × 10 <sup>-17</sup>	—	W
Time Response <sup>D</sup>							
Anode Pulse Rise Time <sup>H</sup>	—	2.2	—	—	2.2	—	ns
Electron Transit Time <sup>J</sup>	—	22	—	—	22	—	ns
Transit Time Spread (TTS) <sup>K</sup>	—	1.2	—	—	1.2	—	ns
Anode Current Stability <sup>L</sup>							
Current Hysteresis	—	0.1	—	—	0.1	—	%
Voltage Hysteresis	—	1.0	—	—	1.0	—	%

## NOTES

- A: Averaged over any interval of 30 seconds maximum.  
 B: The light source is a tungsten filament lamp operated at a distribution temperature of 2856K. Supply voltage is 150 volts between the cathode and all other electrodes connected together as anode.  
 C: The value is cathode output current when a blue filter(Corning CS-5-58 polished to 1/2 stock thickness) is interposed between the light source and the tube under the same condition as Note B.  
 D: Measured with the same light source as Note B and with the anode-to-cathode supply voltage and voltage distribution ratio shown in Table 1 below.  
 E: Measured with the same supply voltage and voltage distribution ratio as Note D after removal of light.  
 F: Measured at the voltage producing the gain of 1 × 10<sup>6</sup>.  
 G: ENI is an indication of the photon-limited signal-to-noise ratio. It refers to the amount of light in watts to produce a signal-to-noise ratio of unity in the output of a photomultiplier tube.

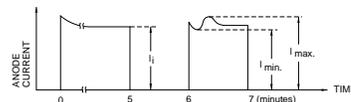
$$ENI = \frac{\sqrt{2q \cdot I_{db} \cdot G \cdot f}}{S}$$

- where q = Electronic charge (1.60 × 10<sup>-19</sup> coulomb).  
 I<sub>db</sub> = Anode dark current(after 30 minute storage) in amperes.  
 G = Gain.  
 f = Bandwidth of the system in hertz. 1 hertz is used.  
 S = Anode radiant sensitivity in amperes per watt at the wavelength of peak response.

- H: The rise time is the time for the output pulse to rise from 10% to 90% of the peak amplitude when the entire photocathode is illuminated by a delta function light pulse.  
 J: The electron transit time is the interval between the arrival of delta function light pulse at the entrance window of the tube and the time when the anode output reaches the peak amplitude. In measurement, the whole photocathode is illuminated.

- K: Also called transit time jitter. This is the fluctuation in electron transit time between individual pulses in the signal photoelectron mode, and may be defined as the FWHM of the frequency distribution of electron transit times.  
 L: Hysteresis is temporary instability in anode current after light and voltage are applied.

$$\text{Hysteresis} = \frac{I_{\max} - I_{\min}}{I_i} \times 100(\%)$$



TPMSB0002EA

### (1)Current Hysteresis

The tube is operated at 750 volts with an anode current of 1 micro-ampere for 5 minutes. The light is then removed from the tube for a minute. The tube is then re-illuminated by the previous light level for a minute to measure the variation.

### (2)Voltage Hysteresis

The tube is operated at 300 volts with an anode current of 0.1 micro-ampere for 5 minutes. The light is then removed from the tube and the supply voltage is quickly increased to 800 volts. After a minute, the supply voltage is then reduced to the previous value and the tube is re-illuminated for a minute to measure the variation.

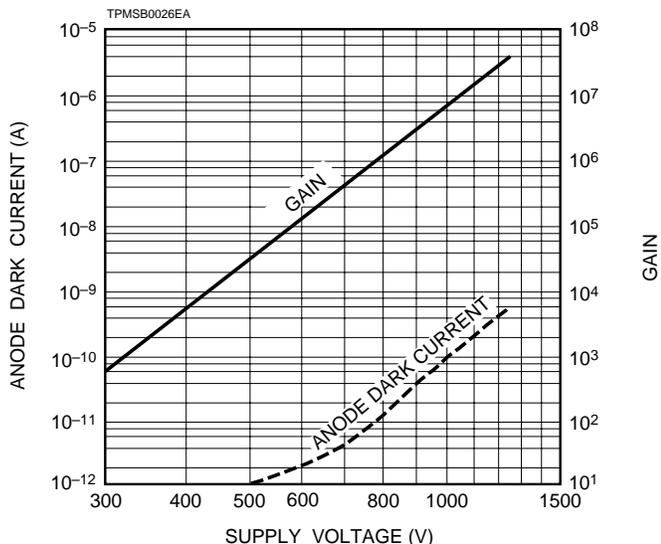
Table 1:Voltage Distribution Ratio

Electrode	K	Dy1	Dy2	Dy3	Dy4	Dy5	Dy6	Dy7	Dy8	Dy9	P
Distribution Ratio	1	1	1	1	1	1	1	1	1	1	1

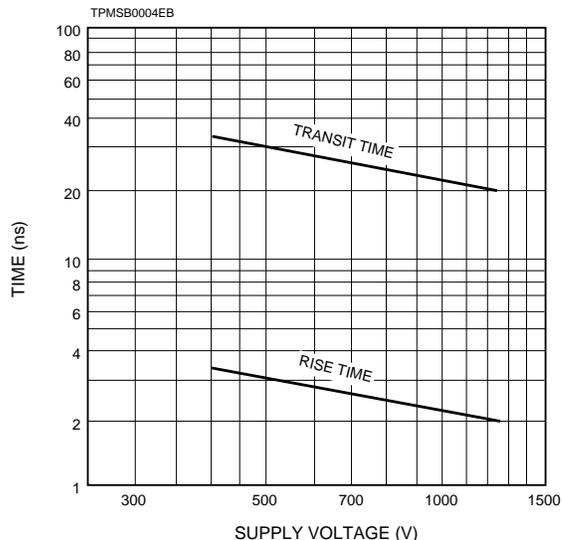
Supply Voltage : 1000Vdc

K : Cathode, Dy : Dynode, P : Anode

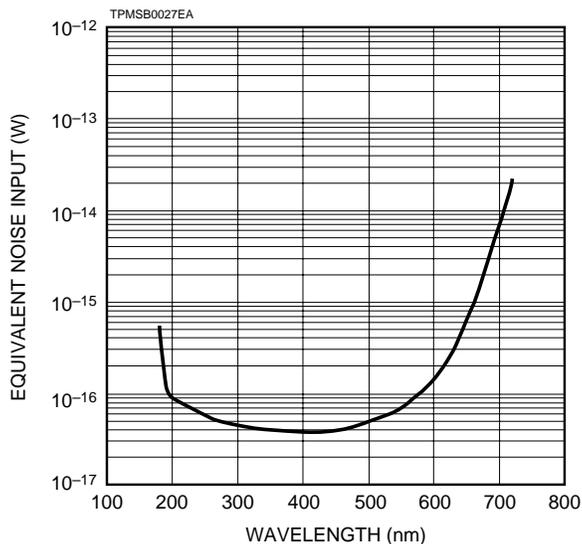
**Figure 2: Typical Gain and Anode Dark Current**



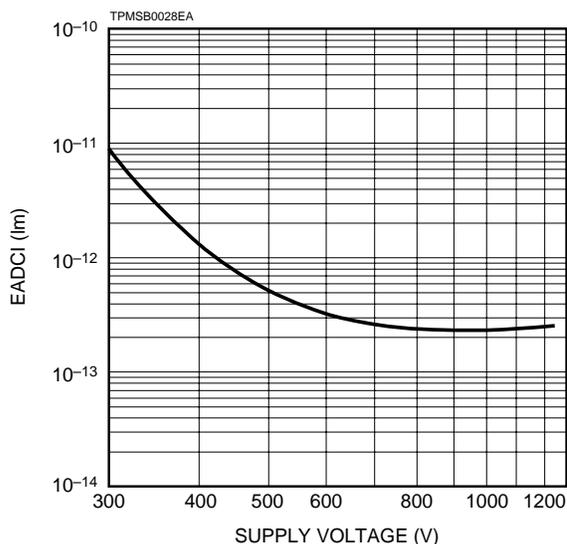
**Figure 3: Typical Time Response**



**Figure 4: Typical ENI vs. Wavelength**

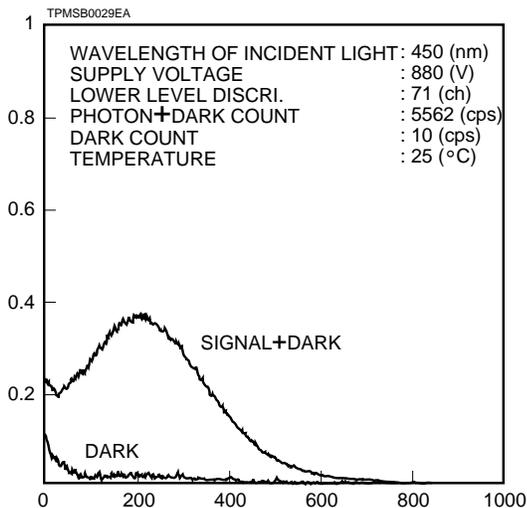


**Figure 5: Typical EADCI (Equivalent Anode Dark Current Input) vs. Supply Voltage**

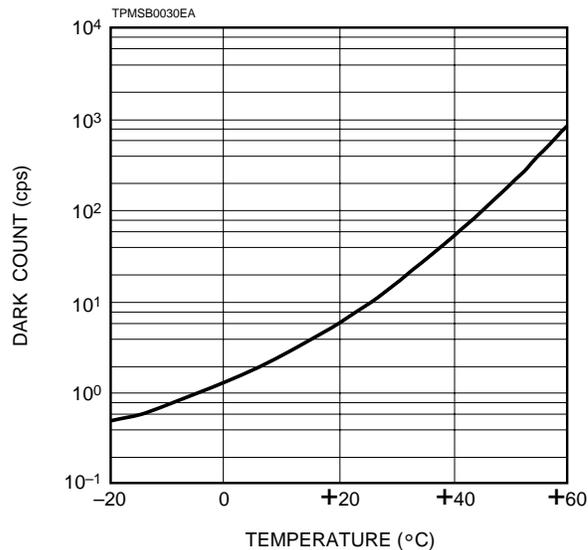


Data shown here, which is given from a relation among supply voltage, anode sensitivity and dark current, serves as a good reference in order to determine the most suitable supply voltage or its range.

**Figure 6: Typical Single Photon Height Distribution for R1527P**

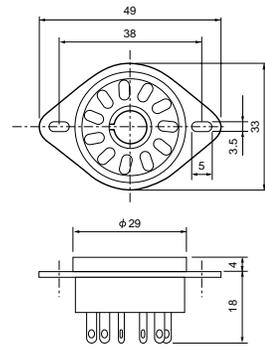
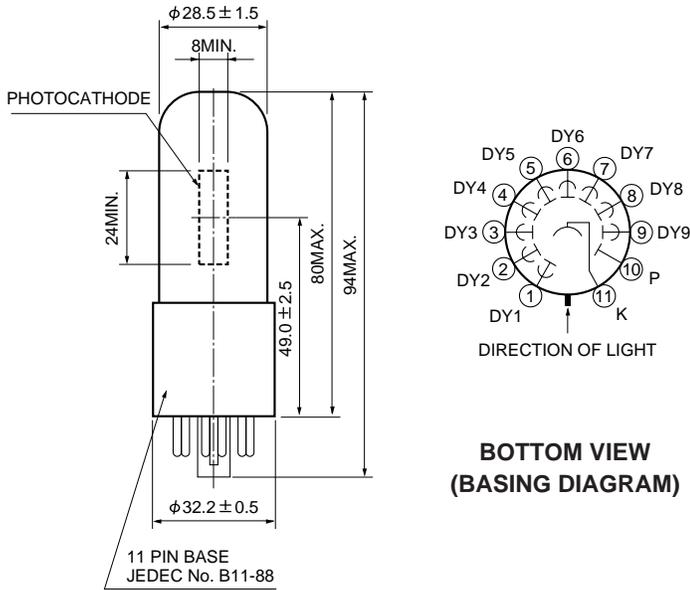


**Figure 7: Typical Temperature Characteristics of Dark Count for R1527P**



# PHOTOMULTIPLIER TUBES R1527, R1527P(For Photon Counting)

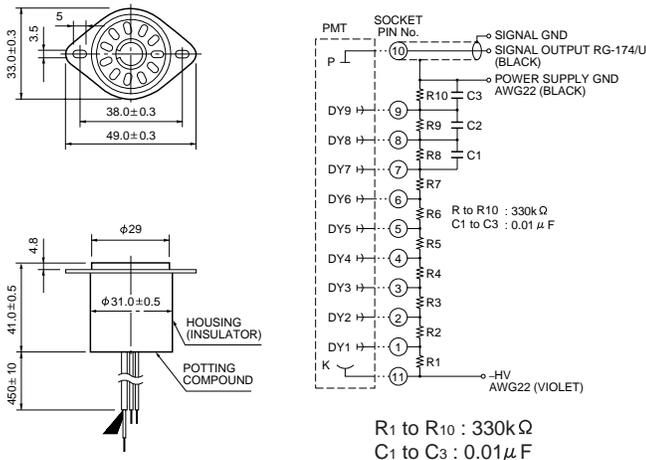
Figure 8: Dimensional Outline and Basing Diagram(Unit: mm)      Figure 10: Socket E678-11A (Optional)



TACCA0064EA

TPMSA0001EA

Figure 9: D Type Socket Assembly E717-21 (Optional)



R1 to R10 : 330kΩ  
C1 to C3 : 0.01μF

TACCA0002ED

※ Hamamatsu also provides C4900 series compact high voltage power supplies and C6270 series DP type socket assemblies which incorporate a DC to DC converter type high voltage power supply.

**Warning—Personal Safety Hazards**  
Electrical Shock—Operating voltages applied to this device present a shock hazard.

## HAMAMATSU

HAMAMATSU PHOTONICS K.K., Ejectron Tube Center

314-5, Shimokanzo, Toyooka-village, Iwata-gun, Shizuoka-ken, Japan, Telephone: (81)539/62-5248, Fax: (81)539/62-2205

U.S.A.: Hamamatsu Corporation: 360 Foothill Road, Bridgewater, N.J. 08807-0910, U.S.A., Telephone: (1)908-231-0960, Fax: (1)908-231-1218

Germany: Hamamatsu Photonics Deutschland GmbH: Arzbergerstr. 10, D-82211 Herrsching am Ammersee, Germany, Telephone: (49)8152-375-0, Fax: (49)8152-2658

France: Hamamatsu Photonics France S.A.R.L.: 8, Rue du Saule Trapu, Parc du Moulin de Massy, 91882 Massy Cedex, France, Telephone: (33)1 69 53 71 00, Fax: (33)1 69 53 71 10

United Kingdom: Hamamatsu Photonics UK Limited: Lough Point, 2 Gladbeck Way, Windmill Hill, Enfield, Middlesex EN2 7JA, United Kingdom, Telephone: (44)181-367-3560, Fax: (44)181-367-6384

North Europe: Hamamatsu Photonics Norden AB: Färögatan 7, S-164-40 Kista Sweden, Telephone: (46)8-703-29-50, Fax: (46)8-750-58-95

Italy: Hamamatsu Photonics Italia: S.R.L.: Via Della Moia, 1/E, 20020 Arese, (Milano), Italy, Telephone: (39)2-935 81 733, Fax: (39)2-935 81 741

TPMS1007E02  
OCT. 1994

# Gesamtübersicht: Laser Diode Modules (LDM) & HeNe Lasers



			<b>RADIUS 375</b>					
Item Number	Description	Extended Description	Module size	Power (mW)	Spot Size (mm)	Divergence (mrad)	Lead Length (mm)	Connector
1053595	Radius 375-8 375nm 8mW CDRH	Radius 375nm, 8mW, CDRH, 44.5mm Diameter x 218mm Length	44,5 mm dia x218 mm	8	1 x 3	0.6 x 1	1000	5-Pin DIN
1053594	Radius 375-8 375nm 8mW OEM	Radius 375nm, 8mW, OEM, 44.5mm Diameter x 218mm Length	44,5 mm dia x218 mm	8	1 x 3	0.6 x 1	1000	5-Pin DIN

			<b>RADIUS 405</b>					
Item Number	Description	Extended Description	Module size	Power (mW)	Spot Size (mm)	Divergence (mrad)	Lead Length (mm)	Connector
1053310	Radius 405-4 405nm 4mW OEM	Radius 405nm, 4mW, Adjustable Focus, OEM, (Vioflame), 44.5mm Diameter x 218mm Length	44,5 mm dia x218 mm	4,2	4.7 x 1.6	0.2 x 0.3	1000	5-Pin DIN
1051390	Radius 405-25 405nm 25mW CDRH	Radius 405nm, 25mW, Adjustable Focus, with CDRH Control Box, 44.5mm Diameter x 218mm Length	44,5 mm dia x218 mm	25	4.7 x 1.6	0.2 x 0.3	1000	5-Pin DIN
1043000	Radius 405-25 405nm 25mW OEM	Radius 405nm, 25mW, Adjustable Focus, OEM, 44.5mm Diameter x 218mm Length	44,5 mm dia x218 mm	25	4.7 x 1.6	0.2 x 0.3	1000	5-Pin DIN
0223-023-00	Radius 405-25CC 405nm 25mW CC	Radius 405nm, 25mW Constant Current, Adjustable Focus, OEM, (Vioflame), 44.5mm Diameter x 218mm Length	44,5 mm dia x218 mm	25	4.7 x 1.6	0.2 x 0.3	1000	5-Pin DIN
1051505	Radius 405-30EP 405nm 30mW CDR	Radius 405nm, 30mW, Extra Photodiode for power stability and low noise, with CDRH Control Box	44,5 mm dia x218 mm	30	2.9 x 1.0	0.2 x 0.4	1000	5-Pin DIN
1008553	Radius 405-30EP 405nm 30mW OEM	Radius 405nm, 30mW, Extra Photodiode for power stability and low noise, OEM, 44.5mm Diameter x 218mm Length	44,5 mm dia x218 mm	30	2.9 x 1.0	0.2 x 0.4	1000	5-Pin DIN

			<b>RADIUS 635</b>					
Item Number	Description	Extended Description	Module size	Power (mW)	Spot Size (mm)	Divergence (mrad)	Lead Length (mm)	Connector
1056830	Radius 635-25 635nm 25mW Adj	Radius 635nm, 25mW, OEM, Adjustable Focus, Beam Size ~2mm, Laser Size 44.5mm Diameter x 218mm Length	44,5 mm dia x218 mm	25	1	1,3	1000	5-Pin DIN
1051385	Radius 635-25 635nm 25mW CDRH	Radius 635nm, 25mW with CDRH Control Box, 44.5mm Diameter x 218mm Length	44,5 mm dia x218 mm	25	1	1,3	1000	5-Pin DIN
1058455	Radius 635-25 635nm 25mW MVP	Radius 635nm, 25mW, OEM, 44.5mm Diameter x 218mm Length, Modulation and Variable Power Option	44,5 mm dia x218 mm	25	1	1,3	1000	5-Pin DIN
1008053	Radius 635-25 635nm 25mW OEM	Radius 635nm, 25mW, OEM, 44.5mm Diameter x 218mm Length	44,5 mm dia x218 mm	25	1	1,3	1000	5-Pin DIN

			<b>Miniature Laser Modules</b>					<b>Circular Beam</b>	
Item Number	Description	Extended Description	Module Size	Power (mW)	Spot Size (mm)	Divergence (mrad)	Lead Length (mm)	Connector	
0221-698-01	Sys,VHK2.3-1 635nm 1mW 1mm C	VLM2, 635nm, 0.95mW, Circular Beam ~1mm	14,7 mm dia x34,3 mm	0,95	1,1	0,7	914	none	
31-0441-000	Sys,VLM2.3-1 635nm 1mW 3mm C	VLM2, 635nm, 0.95mW, Circular Beam ~3mm, with Phono Plug Connector	14,7 mm dia x34,3 mm	0,95	3	0,4	990	Phono-Mono	
0222-458-00	Sys,VLM3.3-1 635nm 1mW C Adj	VLM3, 635nm, 1mW, Beam Size ~3mm, ~Circular, Miniature OEM package, Adjustable Focus with port to add thread lock, No leads - use Power Pins. Label shipped loose.	9,53 mm dia	1	3	0,4	6	none	
0222-200-00	Sys,VMB2.3-5 635nm 4.2mW C CW	VLM2, 635nm, 4.2mW, Circular Beam ~1mm	14,7 mm dia	4,2	1,2	0,7	914	none	
0221-700-01	Sys,VHK2.3-5 635nm 5mW C CW	VLM2, 635nm, 5mW, Circular Beam ~1.1mm	14,7 mm dia	5	1,1	0,7	914	none	
0222-021-01	Sys,VMB2.3-11 635nm 10mW C CW	VLM2, 635nm, 10.5mW, Circular Beam ~1mm	14,7 mm dia	10,5	1,3	0,7	914	none	
0222-002-01	Sys,VLM3.5-2 650nm 1.6mW C SPC	VLM3, 650nm, 1.6mW, Circular Beam ~1.3mm, Kapton Tape on body for electric isolation, Epoxy Back Strain Relief, Internal 3.3 volt regulator for protection and stability. Operates at 4.5-6 VDC	9,53 mm dia	1,7	1,3	0,8	914	none	
0220-999-00	Sys,VLM2-1 670nm 1mW 3mm C	VLM2, 670nm, 1mW, Circular 3mm Beam	14,7 mm dia	0,95	3	0,4	914	none	
0221-460-00	Sys,VLM2-1 670nm 1mW 3mm C MVP	VLM2, 670nm, 0.95mW, Circular Beam 3mm, Modulation and Variable Power Control on third lead, Recommend 6VDC Operatio	14,7 mm dia	0,95	3	0,4	914	none	
31-0425-000	Sys,VLM2-1 670nm 1mW 3mm C Plg	VLM2, 670nm, 0.9mW, Circular Beam 3mm, with Phono Plug Connector	14,7 mm dia	0,95	3	0,4	990	Phono-Mono	
0222-881-00	Sys,VLM3-1 670nm 1mW C Conn	VLM3, 670nm, 0.9mW, Circular Beam ~1mm, 3' leads with connector Molex 39-01-3029	9,53 mm dia	0,95	1.1 x 1	1 x 0.7	76.2	Molex 39-01-3029	
0221-005-00	Sys,VLM2-3 670nm 2.3mW Circ	VLM2, 670nm, 2.3mW, Circular Beam 3mm	14,7 mm dia	2,3	3	0,4	914	none	
0221-831-00	Sys,VHK2-5 670nm 4.9mW C	VLM2, 670nm, 4.9mW, Circular Beam ~1.1mm	14,7 mm dia	4,9	1,1	0,7	914	none	



### Miniature Laser Modules

### Elliptical Beam

Item Number	Description	Extended Description	Module Size	Power (mW)	Spot Size (mm)	Divergence (mrad)	Lead Length (mm)	Connector
0221-814-00	Sys,VLM3.3-3 635nm 2.5mW E CW	VLM3, 635nm, 2.5mW, Elliptical Beam ~4.6 x 1.3 mm	9,53 mm dia	2,5	4.6 x 1.3	0.2 x 0.7	914	none
0221-534-00	Sys,VLM2.3-5 635nm 4.2mW E CW	VLM2, 635nm, 4.2mW, Elliptical Beam ~5.8 x 1.7mm	14,7 mm dia	4,2	5.8 x 1.7	0.2 x 0.6	914	none
0221-895-01	Sys,VLM2.3-11 635nm 10mW E CW	VLM2, 635nm, 10.5mW, Elliptical Beam ~5.8 x 1.7mm	14,7 mm dia	10,5	5.8 x 1.7	0.2 x 0.6	914	none
1051904	Sys,VLM2.3-21 635nm 21mW E CW	VLM2, 635nm, 21mW, Elliptical Beam ~5.8 x 1.7mm	14,7 mm dia	21	5.8 x 1.7	0.2 x 0.6	914	none
31-0607-000	Sys,VLM3.5-4 650nm 4mW E CW	VLM3, 650nm, 4mW, CW, Elliptical ~4 x 1 mm beam, with phono connector	9,53 mm dia	4	4 x 1.1	0.3 x 1.0	990	Phono-Mono
0222-580-01	Sys,VLM3.5-1 650nm 1mW E Reg	VLM3, 650nm, 0.9mW, Elliptical Beam, Internal 3.3 volt regulator for protection and stability, Case at 3.3Volts. Operates at 4.5 - 6 VDC	9,53 mm dia	0,95	1 x 3.7	0.3 x 1.0	914	none
0222-764-00	Sys,VLM2.6-25L 660nm 25mW E CW	VLM2, 660nm, 25mW, Elliptical Beam ~0.5 x 1.3mm, Laser Case at Ground Potential	14,7 mm dia	25	0.5 x 1.3	1.7 x 0.7	914	none
0221-023-00	Sys,VLM2-1 670nm 1mW Ellip	VLM2, 670nm, 0.9mW, Elliptical Beam ~3.3 x 1mm	14,7 mm dia	0,95	3.3 x 1	0.3 x 1.0	914	none
0220-970-00	Sys,VLM3-1 670nm 1mW Ellip	VLM3, 670nm, 0.9mW, Elliptical Beam ~4.6 x 1.3mm	9,53 mm dia	0,95	4.6 x 1.3	0.2 x 0.7	914	none
0221-202-00	Sys,VLM2-5 670nm 4.2mW E MVP	VLM2, 670nm, 4.2mW, Elliptical Beam ~4 x 1.2mm, Modulation and Variable Power Control on third lead, Recommend 6VDC	14,7 mm dia	4,2	4 x 1.2	0.3 x 0.8	914	none
0220-986-00	Sys,VLM2-5 670nm 4.2mW Ellip	VLM2, 670nm, 4.2mW, Elliptical Beam ~1 x 3mm	14,7 mm dia	4,2	3 x 1	0.3 x 1.0	914	none
0220-968-00	Sys,VLM3-3 670nm 2.5mW E	VLM3, 670nm, 2.5mW, Elliptical Beam ~1 x 4mm	9,53 mm dia	4,2	4 x 1	0.2 x 0.7	914	none
0223-038-00	Sys,VLM2-8 670nm 7.5mW SPC	VLM2, 670nm, 7.5mW, Elliptical Beam ~1 x 3mm, Shielded Cable	14,7 mm dia	7,5	3.4 x 1.3	0.3 x 0.8	305	none
0222-929-00	Sys,VLM2 785nm 15mW Ellip	VLM2, 785nm, 15mW, Elliptical Beam ~2.7 x 1.2mm, CW	14,7 mm dia	15	2.7 x 1.2	0.4 x 0.9	914	none
1006427	Sys,VLM2 785nm 40mW ADJ Power	VLM2, 785nm, 40mW, Adjustable Power with back panel potentiometer, special foc. 4.5mm X 1.5mm at 965mm distance, Third wire for laser current sense with 10mV equals ~1ma of laser drive	14,7 mm dia	40	@ 965mm	Special	267	none



### Adjustable Focus Laser Modules

Item Number	Description	Extended Description	Module Size	Power (mW)	Spot Size (mm)	Divergence (mrad)	Lead Length (mm)	Connector
31-0458-000	Sys,FVLM2 635nm 1mW C CW Adj	VLM2, 635nm, 0.95mW, Adjustable Focus, Circular Beam 3mm, Phono Plug Connector	8 ( 14,7 mm dia x max 51	0,95	3	0,4	990	Phono-Mono
0220-862-00	Sys,FVLM2 670nm 1mW C Adj	VLM2, 670nm, 0.9mW, Adjustable Focus, Circular Beam ~3mm	8 ( 14,7 mm dia x max 51	0,95	3	0,4	914	none
0222-287-01	Sys,FVLM3 650nm 1mW C Adj OEM	VLM3, 650nm, 1mW, Circular Beam ~3mm, Adjustable Focus, Miniature OEM style with exposed PCB	8 ( 14,7 mm dia x max 51	1	3	Adjustable	914	none
0223-132-00	Sys,FVMB4 670nm 1mW E VP Adj	VLM4, 670nm, 1mW, Adjustable Focus, Elliptical Beam ~1.3 x 4.2mm, Variable Power Control on Third Wire, Operates from 4.6-5.6 VDC	8 ( 14,7 mm dia x max 51	1	1.3 x 4.2	Adjustable	914	none
0222-404-00	Sys,FVLM-11mm 670nm 4mW E Adj	VLM, 11mm diameter package, 670nm, 4.2mW, Internal 3.3V Regulator, Elliptical Beam ~1.7 x 5.6 mm, Operates at 4.5-6 VDC, Adj Tool included to change focus, Black Anodized case.	17,78 ( 14,7 mm) dia	4,2	1.7 x 5.6	0.6 x 0.2	152	Switchcraft 3558-2 RCA, Center +
0220-857-00	Sys,FVLM2 670nm 4mW E Adj	VLM2, 670nm, 4.2mW, Adjustable Focus, Elliptical Beam ~4 x 1mm	8 ( 14,7 mm dia x max 51	4,2	4 x 1	0.3 x 1.2	609	none
0223-103-00	Sys,FVLM2 670nm 1mW MVP Adj	VLM2, 670nm, 0.95mW, Adjustable Focus, Elliptical Beam ~2.7 x 1.2mm, Modulation and Variable Power Control on third wire	8 ( 14,7 mm dia x max 51	0,95	4 x 1	Adjustable	609	none
1008538	Sys,FVLM2 635nm 10mW E VP Adj	VLM2, 635nm, 10.5mW, Adjustable Focus, Elliptical Beam ~4.5 x 1.2mm, Variable Power Control on third wire	8 ( 14,7 mm dia x max 51	10	4.5 x 1.2	Adjustable	588	none
31-0532-000	Sys,FVLM2 635nm 4mW E CW Adj	VLM2, 635nm, 4mW, Adjustable Focus, Elliptical Beam ~4.7 x 1.3mm, Phono Plug Connector	8 ( 14,7 mm dia x max 51	4,2	4.7 x 1.3	0.2 x 0.8	990	Phono-Mono



### Line Generator Modules

Item Number	Description	Extended Description	Module Size	Power (mW)	Spot Size (mm)	Divergence (mrad)	Lead Length (mm)	Connector
0221-145-00	Sys,LG2-30Deg 670nm 1.8mW	VLM2 Line Generator, 670nm, 1.8mW, 30 Degree Fan Angle	14,7 mm dia	1,8	1	1mrad x 30deg	914	none
0221-155-00	Sys,LG3-30Deg 670nm 2.5mW	VLM3, Line Generator, 670nm, 2.5mW, 30 Degree Fan Angle	9,5 mm	2,5	1	1mrad x 30deg	914	none
0222-037-00	Sys,LG3-40Deg 635nm 1.5mW	VLM3, Line Generator, 635nm, 1.5mW, 40 Degree Fan Angle	9,5 mm	1,5	1	1mrad x 40deg	914	none
0220-936-00	Sys,Indust LG 60Deg 635nm 2mW	Industrial Line Generator, 635nm, 2mW, 60 Degree Fan Angle, Bright Line	9,5 mm	2	1	1mrad x 60deg	304	none
0220-934-00	Sys,LG2.3-60Deg 635nm 2mW	VLM2, Line Generator, 635nm, 2.5mW, 60 Degree Fan Angle	14,7 mm dia	2,5	1	1mrad x 60deg	914	none
0220-972-00	Sys,LG2.3-60Deg 635nm 2mW	VLM2 Line Generator, 635nm, 1.8mW, 60 Degree Fan Angle	14,7 mm dia	1,8	1	1mrad x 60deg	914	none
0221-144-00	Sys,LG2-60Deg 670nm 4mW	VLM2 Line Generator, 670nm, 4.2mW, 60 Degree Fan Angle	14,7 mm dia	4,2	1	1mrad x 60deg	914	none
0222-603-00	Sys,LG3.3-60Deg 635nm 1mW Spc	VLM3 Line Generator, 635nm, 0.8mW, 60 Degree Fan Angle, Connector AMP 87175-6	9,5 mm	0,95	1	1mrad x 60deg	1000	AMP 87175-6
0222-206-00	Sys,LG3-60Deg 670nm 1.8mW	VLM3, Line Generator, 670nm, 1.8mW, 60 Degree Fan Angle	9,5 mm	1,8	1	1mrad x 60deg	914	none
0221-154-00	Sys,LG3-60Deg 670nm 3.5mW	VLM3 Line Generator, 670nm, 3.5mW, 60 Degree Fan Angle	9,5 mm	3,5	1	1mrad x 60deg	914	none
1038903	Sys,FLG3-80Deg 650nm 1mW Adj	VLM3 Line Generator, 650nm, 1.1mW, 80deg Fan Angle, Adjustable Focus Line Width, custom connector, loose label	9,5 mm	1,1	1	80deg x Adjustable		special
31-0631-000	Sys,Dual X Line 635nm 12mW CW	Dual Line Generator, Cross Hair, 635nm, 12mW	19 ( 22) mm dia x142 mm	12	1	1mrad x 85deg	990	Phono-Mono
0220-566-00	Sys,Indust LG 85Deg 635nm 9mW	Industrial Laser Diode Module Line Generator, 635nm, 9.2mW, 85 Degree Fan Angle	19 ( 22) mm dia x142 mm	9,2	1	1mrad x 85deg	304	none
31-0268-000	Sys,LabLaser 85 Deg 635nm 6mW	LabLaser, 635nm, 6mW, Line Generator, 85 Degree Fan Angle, CW, Phono Plug Connector	19 ( 22) mm dia x142 mm	6	1	1mrad x 85deg	990	Phono-Stereo
0220-971-00	Sys,LG2.3-85Deg 635nm 2mW	VLM2 Line Generator, 635nm, 2.5mW, 85 Degree Fan Angle	9,5 mm	2,5	1	1mrad x 85deg	914	none
0220-866-00	Sys,LG2-85deg 670nm 2mW	VLM2 Line Generator, 670nm, 2.5mW, 85 Degree Fan Angle	9,5 mm	2,5	1	1mrad x 85deg	914	none
0223-062-00	Sys,LG3.3-85deg 635nm 3mW EPX	VLM3 Line Generator, 635nm, 3mW, 85 Degree Fan Angle, Epoxy Wire Strain Relief	9,5 mm	3	1	1mrad x 85deg	914	none
31-0615-000	Sys,LG3.5-85deg 650nm 3.7mW	VLM3, Line Generator, 650nm, 3.7mW, 85 Degree Fan Angle, with Phono Connector	9,5 mm	3	1	1mrad X 85deg	990	Phono-Mono
0221-153-00	Sys,LG3-85D 670nm 3.8mW 85deg	VLM3, Line Generator, 670nm, 3.8mW, 85 Degree Fan Angle	9,5 mm	3,8	1	1mrad x 85deg	914	none
0222-337-00	Sys,LG3 X Line 635nm 2mW Cross	VLM3 Line Generator, Diffractive Cross Hair, 635nm, 2mW, 25deg Fan Angle	9,5 mm	2	1	25deg	914	none
0222-210-00	Sys,LG2 X Line 635nm 1mW Adj	VLM2, Line Generator, Diffractive Cross Hair, 635nm, 1mW, Adjustable Focus Line Width, 25 Degree Fan Angle	14,7 mm dia	0,95	1	25deg x Adjustable	610	none
0222-209-00	Sys,LG2 X Line 635nm 2mW Adj	VLM2, Line Generator, Diffractive Cross Hair, 635nm, 2mW, Adjustable Focus Line Width, 25 Degree Fan Angle	17,8 mm ( 14,5 mm ) dia	2	1	25deg x Adjustable	588	none
0220-845-00	Sys,FLG2.3-30Deg 635nm 1mW Adj	VLM2 Line Generator, 635nm, 1.2mW, Adjustable Focus Line Width, 30 Degree Fan Angle, Label on module body.	17,8 mm ( 14,5 mm ) dia	1,2	1	30deg x Adjustable	609	none
0220-846-00	Sys,FLG2.3-60Deg 635nm 2mW Adj	VLM2 Line Generator, 635nm, 1.8mW, Adjustable Focus Line Width, 60 Degree Fan Angle, Label on module body.	17,8 mm ( 14,5 mm ) dia	1,8	1	60deg x Adjustable	609	none

LabLaser and Industrial								
Item Number	Description	Extended Description	Module Size	Power (mW)	Spot Size (mm)	Divergence (mrad)	Lead Length (mm)	Connector
1062083	Sys,LabLaser 830nm 25mW E MVP	LabLaser, 830nm, 25mW, Elliptical Beam -5.2 x 2.1mm, CW, Phono Plug Connector	19 ( 22) mm dia x142 mm	25	5.2 x 2.1	0.2 x 0.6	1140	Phono-Stereo
0221-159-00	Sys,Indust 670nm 4mW E CW	Industrial Laser Diode Module, 670nm, 4.2mW, Elliptical Beam -3x1mm	19 ( 22) mm dia x142 mm	4.2	3 x 1	0.3 x 1.0	304	none
0221-173-00	Sys,Indust 670nm 2.5mW E CW	Industrial Laser Diode Module, 670nm, 2.5mW, Elliptical Beam -3.2 x 1.0mm	19 ( 22) mm dia x142 mm	2.5	3.2 x 1.0	0.3 x 1.0	173	none
31-0102-000	Sys,LabLaser 635nm 4mW E CW	LabLaser, 635nm, 4mW, Elliptical Beam -5.6 x 1.5mm, CW, Phono Plug Connector	19 ( 22) mm dia x142 mm	4.2	5.6 x 1.5	0.2 x 0.7	990	Phono-Stereo
31-0110-000	Sys,LabLaser 635nm 4mW E MVP	LabLaser, 635nm, 4mW, Elliptical Beam -5.6 x 1.5mm, Modulation and Variable Power Control, Phono Plug Connector	19 ( 22) mm dia x142 mm	4.2	5.6 x 1.5	0.2 x 0.7	990	Phono-Stereo
31-0201-000	Sys,LabLaser 635nm 7mW E CW	LabLaser, 635nm, 7mW, Elliptical Beam -5.6 x 1.5mm, CW, Phono Plug Connector	19 ( 22) mm dia x142 mm	7	5.6 x 1.5	0.2 x 0.7	990	Phono-Stereo
31-0219-000	Sys,LabLaser 635nm 7mW E MVP	LabLaser, 635nm, 7mW, Elliptical Beam -5.6 x 1.5mm, Modulation and Variable Power Control, Phono Plug Connector	19 ( 22) mm dia x142 mm	7	5.6 x 1.5	0.2 x 0.7	990	Phono-Stereo
31-0300-000	Sys,LabLaser 635nm 10mW E CW	LabLaser, 635nm, 10.5mW, Elliptical Beam -5.8 x 1.8mm, CW, Phono Plug Connector	19 ( 22) mm dia x142 mm	10.5	5.8 x 1.8	0.2 x 0.6	990	Phono-Stereo
31-0315-000	Sys,LabLaser 635nm 10mW E MVP	LabLaser, 635nm, 10.5mW, Elliptical Beam -5.8 x 1.8mm, Modulation and Variable Power Control, Phono Plug Connector	19 ( 22) mm dia x142 mm	10.5	5.8 x 1.8	0.2 x 0.6	990	Phono-Stereo
0221-164-000	Sys,Indust 670nm 1mW 3mm C CW	Industrial Laser Diode Module, 670nm, 0.95mW, Circular Beam 3mm	19 ( 22) mm dia x142 mm	0.95	3	0.4	304	none
0221-699-02	Sys,Indust 635nm 3mW C CW	Industrial Laser Diode Module, 635nm, 2.9mW, Circular Beam -1.1 mm	19 ( 22) mm dia x142 mm	2.9	1.1	0.7	304	none
31-0128-000	Sys,LabLaser 635nm 4mW C CW	LabLaser, 635nm, 4.9mW, Circular Beam -1.3mm, CW, Phono Plug Connector	19 ( 22) mm dia x142 mm	4.9	1.3	0.7	990	Phono-Stereo
31-0136-000	Sys,LabLaser 635nm 4mW C MVP	LabLaser, 635nm, 4.9mW, Circular Beam -1.2mm, Modulation and Variable Power Control, Phono Plug Connector	19 ( 22) mm dia x142 mm	4.9	1.2	0.8	990	Phono-Stereo
31-0144-000	Sys,LabLaser ULN 635nm 5mW C	LabLaser, ULN, Ultra-Low Noise -0.05% RMS, 635nm, 5mW, Circular Beam -1.3mm	19 ( 22) mm dia x142 mm	5	1.3	0.8	990	Phono-Stereo
31-0227-000	Sys,LabLaser 635nm 7mW C CW	LabLaser, 635nm, 7mW, Circular Beam -1.3mm, CW, Phono Plug Connector	19 ( 22) mm dia x142 mm	7	1.3	0.8	990	Phono-Stereo
31-0235-000	Sys,LabLaser 635nm 7mW C MVP	LabLaser, 635nm, 7mW, Circular Beam -1.3mm, Modulation and Variable Power Control, Phono Plug Connector	19 ( 22) mm dia x142 mm	7	1.3	0.8	990	Phono-Stereo
31-0526-000	Sys,LabLaser 635nm 10mW C CW	LabLaser, 635nm, 10.5mW, Circular Beam -1.3mm, CW, Phono Plug Connector	19 ( 22) mm dia x142 mm	10.5	1.3	0.8	990	Phono-Stereo
31-0334-000	Sys,LabLaser 635nm 10mW C MVP	LabLaser, 635nm, 10.5mW, Circular Beam -1.3mm, Modulation and Variable Power Control, Phono Plug Connector	19 ( 22) mm dia x142 mm	10.5	1.3	0.8	990	Phono-Stereo

Accessories Laserdiodemodules		
Item Number	Description	Extended Description
0221-437-00	Sys,AM-2 Adj Mount, VLM2 15mm	Mount, Laser Diode Module, Adjustable for VLM2 Modules, 14.8mm, 37.5 x 12.5 x 48.3mm
0221-448-00	Sys,AM-3 Adj Mount, VLM3 9mm	Mount, Laser Diode Module, Adjustable for VLM3, 9.5mm, 37.5 x 12.5 x 48.3mm
0221-449-00	Sys,AM-1 Adj Mount, Lab 19mm	Mount, Laser Diode Module, Adjustable for LabLaser or Industrial Modules, 19mm, 37.5 x 12.5 x 48.3mm
31-1605-000	Mount,4 Axis LabLaser(53-1939)	Mount, Laser Diode Module, LabLaser, 4-axis fine adjust. +2deg angle adj. +3.5mm X-Y adjustment, universal. Recommend also buy 53-1962 Adaptor.
31-1613-000	Mount,9mm,ADJ,metric,(53-1855)	Mount, Laser Diode Module, Adjustable for VLM3, 9.5mm, 37.5 x 12.5 x 48.3mm, thumbscrews, M4 hole pattern. Old Catalog Part #53-1855
31-1621-000	Mount,15mm ADJ metric(53-1871)	Mount, Laser Diode Module, VLM, 14.8mm, M4 metric hole pattern, adjustable tip-tilt 15deg, Thumbscrews, Size 37.5 x 12.5 x 48.3 mm, Old Catalog Part#53-1871
31-1639-000	Mount,19mm LabLaser, (53-1897)	Mount, Laser Diode Module, Adjustable for LabLaser, 19mm, 37.5 x 12.5 x 48.3mm, thumbscrews, M4 hole pattern. Old Catalog Part #53-1897
31-1644-000	Mount,9mm,ADJ, 8-32 (61-1855)	Mount, Laser Diode Module, Adjustable for VLM3, 9.5mm, 37.5 x 12.5 x 48.3mm, thumbscrews, 8-32 hole pattern. Old Catalog Part #61-1855
31-1654-000	Mount,19mm LabLsr US(61-1897)	Mount, Laser Diode Module, LabLaser 19mm, 8-32 inch hole pattern, adjustable tip-tilt 15deg, Thumbscrews, Size 37.5 x 12.5 x 48.3 mm, Old Catalog Part#61-1897
31-1662-000	Mount,15mm VLM2 US (61-1871)	Mount, Laser Diode Module, VLM, 14.8mm, 8-32 inch hole pattern, adjustable tip-tilt 15deg, Thumbscrews, Size 37.5 x 12.5 x 48.3 mm, Old Catalog Part#61-1871
31-1670-000	Mount Base 8-32, M4 (53-1913)	Mounting Base, Universal, M4/8-32, 66 x 50.8 x 9.5 mm.
31-1712-000	Adaptor,LabLaser 19mm(53-1962)	Adaptor for 19mm LabLaser for Mount 53-1939. Old Catalog Part#53-1962
31-1001-000	Sys,LDM Power Supply 5 VDC	Power Supply, Laser Diode Module, Desk Top, Mount, 5VDC, 1.5amp
31-1050-000	Sys,LabLaser Power Supply 6VDC	Power Supply, LabLaser, 6VDC, 250ma, Adjustable Power Control for MVP lasers, Key Switch, 5-Second Delay, Emission Indicator, Interlock, 180-260VAC, 120x76x48 mm
2109-0119	Plug,3.5mm Stereo	Phono Plug to take Laser Diode Module with leads and add the connector to work with the LabLaser 31-1001 or 31-1050 power supplies.
31-1068-000	Cable,Modulation,LabLaser, BNC	Modulation Cable to connect LabLaser Laser Diode Module (with installed Modulation Option) to the 31-1050-000 Power Supply. The power supply front panel knob will not control the laser power. Laser is controlled via BNC input on Modulation Cable.



### OEM Laserdiodenmodule für spezielle Anforderungen

Neben einer Auswahl von standardisierten Laserdiodenmodulen im violetten und roten Bereich bietet COHERENT auch kundenspezifische Lösungen für Ihre OEM Anwendung. Die typischen Wellenlängen im roten und nahen infraroten sowie auch im violetten Bereich können mit verschiedenen Strahlprofilen, Gehäusen und Verkabelungen kombiniert werden. Die jeweiligen Module sind CE-zertifiziert und den entsprechenden Laserklassen zugeordnet. Auch bei den OEM-Modulen setzen wir unsere patentierte Microblaze Technologie ein, um runde Strahlprofile mit einem M2 = 1,1 zu erzeugen. Eine einstellbare Fokussier-Optik kann ebenfalls in die Module integriert werden. In vielen Fällen kann so der bisher eingesetzte HeNe Laser durch ein kostengünstiges, kompaktes Diodenmodul ersetzt werden.

Um Ihren speziellen Anforderungen im industriellen aber auch im wissenschaftlichen Bereich gerecht zu werden, sind folgende Eckdaten wichtig, um eine optimal angepasste Lösung zu finden:

- Leistung und Strahlprofil (Rund, Elliptisch, Linie)
- Divergenz bzw. benötigter Fokus
- Gehäuseform und Abmaße
- Kabelanschluss und Steckerform
- Netzteil

Sprechen Sie uns an. Wir finden für fast jede Laseranwendung die geeignete Strahlquelle.





## Helium Neon Lasers

31-2009-000	LSR,Red HeNe 0.8mW, 7" Linear	Helium Neon Laser, Red 632.8nm, 0.8mW, Linear, 0.46mm Beam, Length 178mm, Diameter 31.75mm use PSU 31-2470
31-2470-000	Power Supply, HeNe 115/230VAC	HeNe Power Supply with Key Switch, Interlock, and Emission Indicator, 115/230 VAC
31-2017-000	LSR,Red HeNe 0.8mW, 7" Random	Helium Neon Laser, Red 632.8nm, 0.8mW, Random, 0.46mm Beam, Length 178mm, Diameter 31.75mm use PSU 31-2470
31-2470-000	Power Supply, HeNe 115/230VAC	HeNe Power Supply with Key Switch, Interlock, and Emission Indicator, 115/230 VAC
31-2025-000	LSR,Red HeNe 2mW, 12.5" Linear	Helium Neon Laser, Red 632.8nm, 2mW, Linear, 0.79mm Beam, Length 315mm, Diameter 31.75mm use PSU 31-2462
31-2462-000	Power Supply, HeNe 115/230VAC	HeNe Power Supply with Key Switch, Interlock, and Emission Indicator, 115/230 VAC
31-2033-000	LSR,Red HeNe 2mW, 12.5" Random	Helium Neon Laser, Red 632.8nm, 2mW, Random, 0.79mm Beam, Length 315mm, Diameter 31.75mm use PSU 31-2462
31-2462-000	Power Supply, HeNe 115/230VAC	HeNe Power Supply with Key Switch, Interlock, and Emission Indicator, 115/230 VAC
31-2041-000	LSR,Red HeNe 4mW, 15.5" Linear	Helium Neon Laser, Red 632.8nm, 4mW, Linear, 0.80mm Beam, Length 396mm, Diameter 31.75mm use PSU 31-2405
31-2405-000	Power Supply, HeNe 115/230VAC	HeNe Power Supply with Key Switch, Interlock, and Emission Indicator, 115/230 VAC
31-2059-000	LSR,Red HeNe 4mW, 15.5" Random	Helium Neon Laser, Red 632.8nm, 4mW, Random, 0.80mm Beam, Length 396mm, Diameter 31.75mm use PSU 31-2405
31-2405-000	Power Supply, HeNe 115/230VAC	HeNe Power Supply with Key Switch, Interlock, and Emission Indicator, 115/230 VAC
31-2066-000	LSR,Red HeNe 7mW, 18" Linear	Helium Neon Laser, Red 632.8nm, 7mW, Linear, 1.02mm Beam, Length 456mm, Diameter 31.75mm use PSU 31-2454
31-2454-000	Power Supply, HeNe 115/230VAC	HeNe Power Supply with Key Switch, Interlock, and Emission Indicator, 115/230 VAC
31-2074-000	LSR,Red HeNe 7mW, 18" Random	Helium Neon Laser, Red 632.8nm, 7mW, Random, 1.02mm Beam, Length 456mm, Diameter 31.75mm use PSU 31-2454
31-2454-000	Power Supply, HeNe 115/230VAC	HeNe Power Supply with Key Switch, Interlock, and Emission Indicator, 115/230 VAC
31-2082-000	LSR,Red HeNe 10mW, 19" Linear	Helium Neon Laser, Red 632.8nm, 10mW, Linear, 0.46mm Beam, Length 484mm, Diameter 31.75mm use PSU 31-2439
31-2439-000	Power Supply, HeNe 115/230VAC	HeNe Power Supply with Key Switch, Interlock, and Emission Indicator, 115/230 VAC
31-2090-000	LSR,Red HeNe 10mW, 19" Random	Helium Neon Laser, Red 632.8nm, 10mW, Random, 0.46mm Beam, Length 484mm, Diameter 31.75mm use PSU 31-2439
31-2439-000	Power Supply, HeNe 115/230VAC	HeNe Power Supply with Key Switch, Interlock, and Emission Indicator, 115/230 VAC
31-2108-000	LSR,Red HeNe 17mW, 25" Linear	Helium Neon Laser, Red 632.8nm, 17mW, Linear, 0.95mm Beam, Length 637mm, Diameter 31.75mm use PSU 31-2447
31-2447-000	Power Supply, HeNe 115/230VAC	HeNe Power Supply with Key Switch, Interlock, and Emission Indicator, 115/230 VAC
31-2140-000	LSR,Red HeNe 35mW, 40.6" Lin	Helium Neon Laser, Red 632.8nm, 35mW, Linear, 1.25mm Beam, Size 1030 x 79 x 66mm use PSU 31-2488
31-2488-000	Power Supply, HeNe 115/230VAC	HeNe Power Supply with Key Switch, Interlock, and Emission Indicator, 115/230 VAC
31-2196-000	LSR,Red HeNe 17mW, 25" Random	Helium Neon Laser, Red 632.8nm, 17mW, Random, 0.95mm Beam, Length 637mm, Diameter 31.75mm use PSU 31-2447
31-2447-000	Power Supply, HeNe 115/230VAC	HeNe Power Supply with Key Switch, Interlock, and Emission Indicator, 115/230 VAC
31-2207-000	LSR,Orange HeNe 2mW 15.5" Rdm	Helium Neon Laser, Orange 612.0nm, 2mW, Random, 0.80mm Beam, Length 396mm, 44.5mm Diameter use PSU 31-2405
31-2405-000	Power Supply, HeNe 115/230VAC	HeNe Power Supply with Key Switch, Interlock, and Emission Indicator, 115/230 VAC
31-2230-000	LSR,Yellow HeNe 2mW 18" Random	Helium Neon Laser, Yellow 594.1nm, Random, 0.75mm Beam, Length 456mm use PSU 31-2413
31-2413-000	Power Supply, HeNe 115/230VAC	HeNe Power Supply with Key Switch, Interlock, and Emission Indicator, 115/230 VAC
31-2264-000	LSR,Green HeNe 0.3mW 15.5" Rdm	Helium Neon Laser, Green 543.5nm, 0.3mW, Random, 0.66mm Beam, Length 315mm, 44.5mm Diameter use PSU 31-2421
31-2421-000	Power Supply, HeNe 115/230VAC	HeNe Power Supply with Key Switch, Interlock, and Emission Indicator, 115/230 VAC for HeNe Green 543.5nm, 0.3mW, Random
31-2298-000	LSR,Green HeNe 1mW 20" Linear	Helium Neon Laser, Green 543.4nm, 1mW, Linear, 0.86mm Beam, Length 510mm, 44.5mm Diameter use PSU 31-2439
31-2439-000	Power Supply, HeNe 115/230VAC	HeNe Power Supply with Key Switch, Interlock, and Emission Indicator, 115/230 VAC, for
31-2772-000	LSR,Green HeNe 2mW 20" Random	Helium Neon Laser, Green 543.5nm, 2mW, Random, 0.88mm Beam, Length 510mm, 44.5mm Diameter use PSU 31-2439
31-2439-000	Power Supply, HeNe 115/230VAC	HeNe Power Supply with Key Switch, Interlock, and Emission Indicator, 115/230 VAC

Helium Neon Laser Accessories		
31-1888-000	Mount,HeNe,Tilt (53-1491)	Mount, HeNe, 32.51mm, 1/4-20 hole pattern, adjustable tip-tilt, Size 190 x 80 OD mm, Old Catalog Part#53-1491
31-1720-000	Mount,HeNe,Var,US (61-2937)	Mount, HeNe, 44mm, 8-32 inch hole pattern, adjustable tip-tilt 17deg, Thumbscrews, Size 80 x 20 x 88 mm, Old Catalog Part#61-2937
31-1738-000	Mount,HeNe,Var,metric(53-2937)	Mount, HeNe, 44mm, M4 metric hole pattern, adjustable tip-tilt 17deg, Thumbscrews, Size 80 x 20 x 88 mm, Old Catalog Part#53-2937
31-1746-000	Mount,HeNe,Adj,8-32 (61-1483)	Mount, HeNe, 32.51mm, 8-32 hole pattern, adjustable tip-tilt, Size 100 x 60 x 61 mm, Old Catalog Part#61-1483
31-2538-000	Adapter,C Ring with screws	Adaptor for front of HeNe or Radius System
31-2505-000	Beam Expander, HeNe, Zoom	Beam Expander, Zoom 1X to 8X, Adj Focus, 3mm input
31-2512-000	Beam Expander, HeNe (x10)	Beam Expander, Adj Focus, 2mm input
31-2520-000	Beam Expander, HeNe (x5)	Beam Expander, Adj Focus, 4mm input

### Kontakt:

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**Laserzubehör**

**Dieselstraße 5b**

**64807 Dieburg**

**Fax: +49-(0)6071-968-499**

# Phillips Scientific

## Octal Discriminator

### NIM MODEL 705

## FEATURES

- INDIVIDUAL THRESHOLD AND WIDTH CONTROLS
- LINEAR SUMMED OUTPUT
- BOTH FAST VETO AND BIN GATE
- LOW COST
- EIGHT (8) CHANNELS IN A SINGLE WIDTH NIM MODULE

## DESCRIPTION

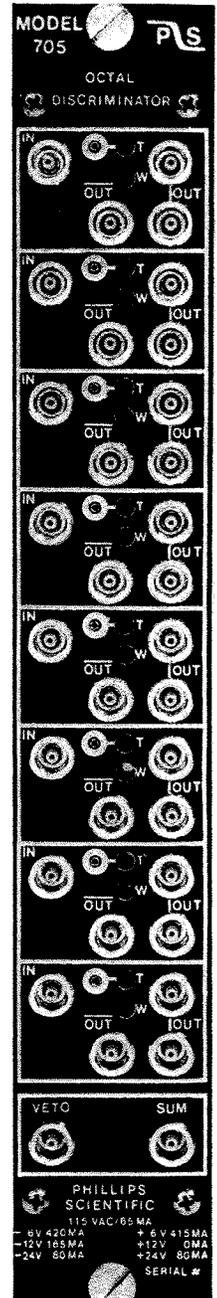
The Model 705 was specifically designed for modern experiments with large counter arrays, offering high performance and reliability at a reasonable cost. The 705 features eight (8) totally independent channels with individual threshold and width controls. In addition, a fast veto input and a summed output are common to all channels.

Each channel has a threshold adjustment continuously variable from  $-10\text{ mV}$  to  $-1\text{ Volt}$  with a front panel test point providing a DC voltage ten (10) times the actual threshold setting. Likewise, each channel has a non-updating regeneration circuit for adjustable output widths from  $6\text{ nSEC}$  to  $150\text{ nSEC}$ .

A unique summed output is common to all eight channels providing  $-1\text{ mA}$  of current for each activated channel, thus allowing a fast decision to be made on the number of channels simultaneously hit. Up to 16 channels can be "OR'D" directly by cable to other summed outputs allowing a versatile scheme to form a trigger.

A fast veto input allows simultaneous inhibiting of all channels to reject unwanted events early in the system. Similarly, a bin gate will inhibit the entire module when applied via the rear connector.

The outputs are the current source type with one pair of negative bridged outputs and one complement for each channel. When only one output of the bridged pair is used, a double-amplitude NIM pulse ( $-32\text{mA}$ ) is generated, when both connectors are used normal NIM levels ( $-16\text{mA}$ ) are produced. The outputs have crisp, clean transitions, and their shapes are unaffected by the loading conditions of the other outputs.



Phillips Scientific

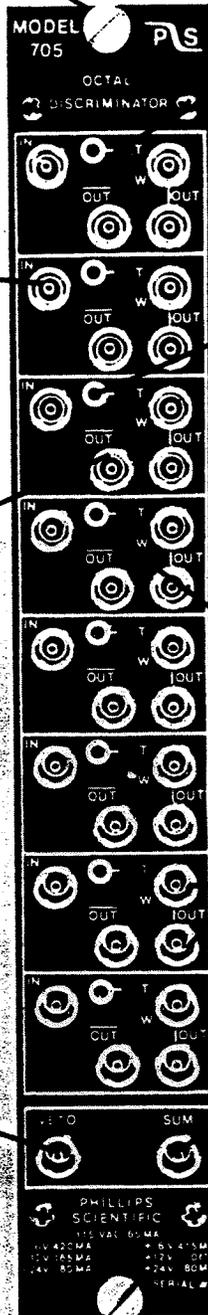
A THEORY DEVELOPMENT COMPANY  
150 Hilltop Road • Ramsey, NJ 07446 • (201) 934-8015 • Fax (201) 934-8269



MODEL 705 OCTAL DISCRIMINATOR

(FRONT PANEL DESCRIPTION)

Standard #1 NIM Packaging  
in accordance with  
TID-20893



Threshold Control; 15-turn  
Screwdriver Adjustment,  
Variable from -25 mV  
to -1 Volt

50 Ohm Input

Threshold Monitor; Test  
Point provides a DC  
Voltage 10 times the  
actual Threshold Setting  
(-250 mV to -10 V)

One Complemented NIM Output.  
Quiescently -16 mA (-800 mV)  
Goes to 0 mA (0 Volts) during  
output.

Output Width Control;  
15-turn Screwdriver  
Adjustment, Variable from  
6 nSec to 150 nSec.

Double amplitude bridged  
output; -32 mA (-1.6 Volts  
across 50 ohms, -.8 Volt  
with two 50 ohm terminations)

Fast Inhibit Input accepts  
normal NIM logic (-500 mV)  
50 Ohm Impedance

Linear summed output;  
-1 mA/step. (-50 mV across  
50 ohms)

**NOTE:** Bin Gate Enable/  
Disable Switch on Rear  
Panel permits Inhibiting  
via Bin Connector.

Voltage and Current  
Requirements

**Phillips Scientific**

13 Ackerman Avenue • Suffern, New York 10901 • USA • (914) 357-9417

# Phillips Scientific

## Logic Unit

# NIM MODEL 755

### FEATURES

- VERSATILE LOGIC MODULE WITH MAJORITY LEVEL SELECTION
- FOUR INDEPENDENT CHANNELS
- 125 MHz RATE CAPABILITY
- DEADTIMELESS UPDATING OUTPUTS
- FAST ANTI-COINCIDENCE CAPABILITY

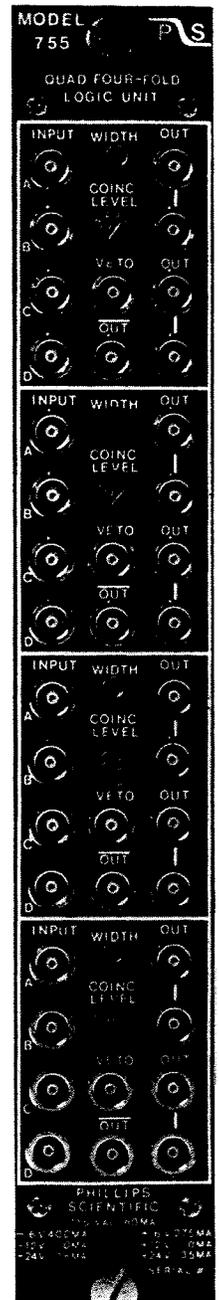
### DESCRIPTION

The model 755 logic unit contains four channels of four input logic with veto in a single width NIM module. Logic AND, OR majority logic, fan-in/fan-out, and anti-coincidence functions can be performed with this versatile module. All functions are direct coupled and operate to over 125 MHz with input overlap times as narrow as 1 nSEC.

Each channel has four logic inputs, an anti-coincidence input, a coincidence level switch, and five outputs with common width control. The inputs are enabled by connecting the input cable to the desired input, eliminating errors often occurring with switched inputs. The setting of the coincidence level switch then determines whether a logic OR, AND, or majority logic function will produce an output.

After the inputs have satisfied the logic function desired, triggering of an updating regenerative stage produces a standardized output pulse, variable from 4 nSEC to 1 uSEC, independent of the input pulse shapes or overlap times. The updating feature ensures deadtimeless operation, while the double-pulse resolution is 7.5 nSEC for fast counting applications.

The outputs are the current source type with two pairs of negative bridged outputs and one complement for each channel. When only one output of a bridged pair is used, a double-amplitude NIM pulse (-32 mA) is generated for driving long cables with narrow pulse widths. The outputs have transition times of typically 1.0 nSEC, and their shapes are virtually unaffected by the loading conditions of the other outputs.



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150 Hilltop Road • Ramsey, NJ 07446 • [201] 934-8015 • Fax [201] 934-8269

## INPUT CHARACTERISTICS

### A, B, C, D<sub>i</sub>

Four inputs per section, LEMO connectors; accepts NIM level logic signals (-500 mV); 50 ohm input impedance direct coupled; input reflections are less than  $\pm 5\%$  for a 1 nSEC rise-time. Inputs are protected against damage from  $\pm 50$  volt input transients. Inputs respond to a 1 nSEC or greater input width.

### Fast Veto:

One input per section, LEMO connector; accepts NIM level logic signal (-500 mV); 50 ohm input impedance, direct coupled; less than  $\pm 5\%$  input reflection for a 1 nSEC risetime, protected against damage  $\pm 50$  volt input transients. Requires a 3.5 nSEC minimum input width in time with the input pulse leading edge to inhibit.

### Bin Gate:

Rear-panel slide switch enables or disables the slow bin gate via the rear connector. Signal levels are in accordance with the TID-20893 standard.

## OUTPUT CHARACTERISTICS

### General:

Five outputs per section, two pairs of negative bridged and one complemented NIM. The two pairs of bridged outputs are quiescently 0 mA and -32 mA during output. (-1.6 V into 50 ohms or -.8 V into 25 ohms). The complemented output is quiescently -16 mA and 0 mA during output. Risetimes and falltimes are less than 1.5 nSEC, and the output pulse shapes are optimized when the bridged outputs are 50 ohm terminated.

### Width Control:

One control per section; 15-turn screwdriver adjustment. Outputs are continuously variable from 4 nSEC to 1 uSEC; better than 0.15%/°C.

### Updating Operation:

The output pulse will be extended if a new input pulse occurs while the output is active. This provides deadtimeless operation and 100% duty cycle can be achieved.

## GENERAL PERFORMANCE

### Functions:

Logic AND, OR, majority logic, and logic fan-in/fan-out. All functions have leading edge inhibit with standardized outputs.

### Rate:

150 MHz minimum, input to output. Typically 160 MHz.

### Double-Pulse Resolution:

Less than 6.5 nSEC; Typically 6 nSEC with output width set at minimum.

### Input to Output Delay:

Less than 8 nSEC.

### Multiple Pulsing:

One and only one output pulse regardless of input pulse amplitude or duration.

### Power Supply Requirements:

-6 V @ 400 mA	+6 V @ 250 mA
-12 V @ 165 mA	+12 V @ 0 mA
-24 V @ 60 mA	+24 V @ 35 mA

115 VAC @ 60 mA

**Note: All currents within NIM specifications limits allowing a full-powered bin to be operated without overloading.**

### Operating Temperature:

0°C to 70°C ambient.

### Packaging:

Standard single width NIM module in accordance with TID-20893 and Section 524.

### Options:

Call Phillips Scientific to find out about available options.

**Phillips Scientific**

ANALOG DEVELOPMENT COMPANY  
150 Hilltop Road • Ramsey, NJ 07446 • (201) 934-8015 • Fax (201) 934-8265

MODEL 755 QUAD FOUR-FOLD MAJORITY LOGIC UNIT  
(FRONT PANEL DESCRIPTION)

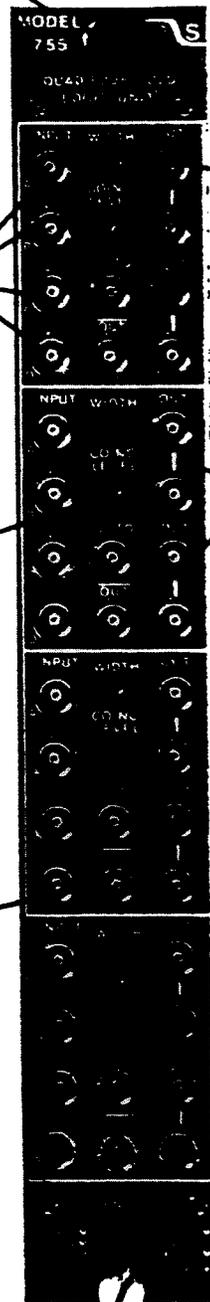
Standard #1 NIM Packaging  
in accordance with  
TID-20893

Four Logic Inputs; Accepts  
Normal NIM Logic (-500 mV)  
50 ohm Impedance

Four Position Coincidence  
Level Switch; Selects  
Logical "OR", "AND",  
or Majority Logic  
Functions.

One Complemented NIM  
Output. Quiescently  
-16 mA (-800 mV). Goes  
to 0 mA (0 Volts) during  
output.

**NOTE:** Bin Gate Enable/  
Disable Switch on Rear  
Panel permits Inhibiting  
via Bin Connector.



Output Width Control;  
15-turn Screwdriver  
Adjustment, Variable from  
4 nSec to 1  $\mu$ Sec.

Two pairs of bridged  
outputs; each pair delivers  
-32 mA (-1.6 Volts across  
50 ohms, -.8 Volt with  
both outputs 50 ohm  
terminated).

Fast Inhibit Input accepts  
normal NIM Logic (-500 mV)  
50 ohm Impedance

Voltage and Current  
Requirements

**Phillips Scientific**

13 Ackerman Avenue • Suffern, New York 10901 • USA • (914) 357-9417

- Ideal for selecting a range of pulse amplitudes from a spectroscopy amplifier for counting on a ratemeter or counter/timer
- Provides the excellent stability, resolution, and dynamic range demanded by high-resolution detectors
- Four operating modes:
  - Integral
  - Normal (independent upper and lower levels)
  - Asymmetric window
  - Symmetric window
- DC-coupled for high counting rates
- SCA output generated when the input signal falls below the lower level



The ORTEC Model 550A Single-Channel Analyzer is ideally suited for selecting a range of output pulse amplitudes from a spectroscopy amplifier for subsequent counting on a ratemeter or a counter/timer. It provides the excellent stability, resolution, and dynamic range needed for measurements with high-resolution germanium and silicon detectors. These same features provide more than adequate performance with scintillation counters, proportional counters, and ionization chambers. The entire instrument is dc-coupled to ensure that the discriminator levels are not affected by changes in the counting rate, even at very high counting rates.

The versatility of the Model 550A is enhanced by four basic operating modes. In the INTEGRAL mode, all input pulse amplitudes above the lower level produce an SCA output logic pulse. This mode is useful for counting all pulses above the noise level, or above a well-defined lower amplitude limit. The INTEGRAL mode can also be used for leading edge timing, or pulse routing logic. In the NORMAL mode, the upper- and lower-level discriminators are independently variable over the full +20 mV to +10 V range. The SCA output is generated only for pulse amplitudes that occur between the upper and lower levels. This mode is useful when a wide range of pulse heights must be selected for counting. In the ASYMMETRIC WINDOW mode, the upper-level dial becomes a window width control with a 0 to +1 V range. The lower-level dial controls the lower limit of the window over a +20 mV to +10 V range. Pulse amplitudes between the upper and lower limits of the window produce an

SCA output. This mode is useful when a narrow range of pulse heights must be selected. In the SYMMETRIC WINDOW mode, the upper-level dial still controls the window width over the range of 0 to +1 V, but the lower-level dial sets the position of the center of the window over a range of +20 mV to +10 V. The SYMMETRIC WINDOW mode is useful when the window has been centered on a peak in the spectrum and it is desirable to widen (or narrow) the window to accept more (or less) of the peak width.

Rear-panel connectors provide separate outputs for the upper- and lower-level discriminators. These logic outputs are generated at the instant the input signal exceeds the corresponding discriminator level. The SCA output logic pulse is generated when the input signal falls through the lower-level threshold.

An external input for the lower-level setting is switch selectable to allow recording the entire pulse-height spectrum utilizing a scanning technique. A narrow window is selected, and an external voltage source is employed to slowly scan the lower level through the 0 to 10 V range. A ratemeter counts the SCA output and draws the spectrum on a strip chart recorder.

# 550A

## Single-Channel Analyzer

### Specifications

#### PERFORMANCE

**DYNAMIC RANGE** 500:1.

**PULSE-PAIR RESOLVING TIME** 100 ns plus output pulse width.

#### THRESHOLD TEMPERATURE

**SENSITIVITY** <0.01% of full scale per °C, from 0 to 50°C, using a NIM Class A power supply (referenced to -12 V).

**WINDOW WIDTH CONSTANCY** Variation <±0.1% of full-scale window width over the +20 mV to +10 V linear input range.

**DISCRIMINATOR NONLINEARITY** <±0.25% of full scale for both discriminators.

#### INDICATORS

**SCA OUT LED** Front-panel LED flashes whenever an SCA output pulse is generated.

#### CONTROLS

**WINDOW OR UPPER LEVEL** Front-panel, 10-turn, locking dial determines the window width (0 to 1 V) in the WINDOW modes, or the upper-level threshold (0 to +10 V) in the NORMAL and INTEGRAL modes.

**LOWER LEVEL** Front-panel, 10-turn, locking dial determines the threshold setting (+20 mV to +10 V) for the lower-level discriminator when the rear-panel LL REF switch is in the INT position. The LOWER-LEVEL control is disabled when the EXT position is selected on the rear-panel LL REF switch.

**INT, ASYM WINDOW, SYM WINDOW, NORM** Front-panel, four-position rotary switch selects one of four operating modes:

**INT** In the INTEGRAL mode, the lower level and upper level are independently adjustable from +20 mV to +10 V. The SCA OUT is generated for all pulse amplitudes exceeding the lower-level threshold.

**NORM** In the NORMAL mode, the lower level and upper level are independently adjustable from +20 mV to +10 V. The SCA OUT is generated for pulse amplitudes that exceed the lower-level threshold, but do not exceed the upper-level threshold.

**ASYM WINDOW** In the ASYMMETRIC WINDOW mode, the **lower limit** of the window is adjustable from +20 mV to +10 V using the LOWER LEVEL dial. The WINDOW dial adjusts the width of the window from 0 to 1 V. The SCA OUT is generated for pulse amplitudes between the upper and lower limits of the window.

**SYM WINDOW** In the SYMMETRIC WINDOW mode, the **center** of the window is adjustable from +20 mV to +10 V using the LOWER LEVEL dial. The WINDOW dial adjusts the width of the window from 0 to 1 V. The SCA OUT is generated for pulse amplitudes between the upper and lower limits of the window.

**INT/EXT LL REF** A rear-panel locking toggle switch selects either the front-panel LOWER LEVEL dial (INT position), or the rear-panel LL REF input (EXT position) for controlling the lower-level threshold.

#### INPUTS

**INPUT** Front-panel BNC connector accepts unipolar or bipolar linear signals for pulse amplitude selection in the range of +20 mV to +10 V (dc-coupled). The minimum input pulse width is 100 ns. The maximum amplitude of signal plus dc offset is ±12 V. Input impedance is approximately 1000 Ω. Front-panel test point wired to the INPUT connector through a 470-Ω resistor.

**IN** Rear-panel BNC connector identical to INPUT connector.

**LL REF** Rear-panel BNC connector accepts a dc voltage from an external source for controlling the lower-level threshold when the INT/EXT LL REF switch is in the EXT position. The input range of -20 mV to -10 V corresponds to a lower-level threshold range of +20 mV to +10 V. The input is overload protected to ±15 V.

#### OUTPUTS

**SCA OUT** Front- and rear-panel BNC connectors provide a NIM-standard, positive logic pulse output: nominally +5 V amplitude and 500-ns width. Output impedance <15 Ω. Front- and rear-panel outputs have separate

output drivers. The output pulse occurs when the trailing edge of the linear input pulse crosses the lower-level threshold. See description under CONTROLS for output logic modes. Front-panel test point wired to the SCA OUT connector through a 470-Ω resistor.

**LL OUT** Rear-panel BNC connector provides a NIM-standard, positive logic pulse output: nominally +5 V amplitude and 500-ns width. Output impedance <15 Ω. The output pulse occurs when the leading edge of the linear input pulse crosses the lower-level threshold (INT or NORMAL modes), or the lower limit of the window (WINDOW modes).

**UL OUT** Rear-panel BNC connector provides a NIM-standard, positive logic pulse output: nominally +5 V amplitude and 500-ns width. Output impedance <15 Ω. The output pulse occurs when the leading-edge of the linear input pulse crosses the upper-level threshold (INT or NORMAL modes), or the upper limit of the window (WINDOW modes).

#### ELECTRICAL AND MECHANICAL

**POWER REQUIRED** +12 V at 75 mA, -12 V at 35 mA.

#### WEIGHT

**Net** 0.9 kg (2.0 lb)

**Shipping** 2.3 kg (5.0 lb)

**DIMENSIONS** NIM-standard single-width module 3.43 X 22.13 cm (1.35 X 4.714 in.) front panel per DOE/ER-0457T.

### Ordering Information

To order, specify:

Model	Description
550A	Single-Channel Analyzer

Specifications subject to change  
011008

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## 572A Amplifier Specifications

### PERFORMANCE

**Gain Range** Continuously adjustable from 1 to 1500.

**Pulse Shape** Semi-Gaussian on all ranges with peaking time equal to  $2.2\tau$  and pulse width at 0.1% level equal to 2.9 times the peaking time.

**Integral Nonlinearity** For 2- $\mu$ s shaping time,  $<\pm 0.05\%$ .

**Noise** Typically  $<5 \mu\text{V}$  for unipolar output referred to the input, using 2- $\mu$ s shaping and Coarse Gain  $\times 100$ .

### Temperature Instability

**Gain**  $\pm 0.0075\%/^{\circ}\text{C}$ , 0 to  $50^{\circ}\text{C}$ .

**DC Level**  $\pm 50 \mu\text{V}/^{\circ}\text{C}$ , 0 to  $50^{\circ}\text{C}$ .

**Bipolar Crossover Walk**  $\pm 3 \text{ ns}$  at 0.5  $\mu\text{s}$  for 50:1 dynamic range, including contribution of an ORTEC Model 552 Single-Channel Analyzer.

**Overload Recovery** Recovers to within 2% of rated output from X300 overload in 2.5 nonoverloaded pulse widths using maximum gain for Unipolar Output. Same recovery from X1000 overload for bipolar.

**Spectrum Broadening** Typically  $<16\%$  FWHM for a  $^{60}\text{Co}$  1.33 MeV gamma line at 85% of full scale for an incoming count rate of 1 to 100,000 counts/s (Unipolar Output, 2- $\mu$ s shaping).

**Spectrum Shift** Peak position shifts typically  $<0.024\%$  for a  $^{60}\text{Co}$  1.33-MeV gamma line at 85% of full scale measured from 1 to 100,000 counts/s (Unipolar Output, 2- $\mu$ s shaping).

### ELECTRICAL AND MECHANICAL

**Power Required** +12 V, 85 mA; -12 V, 50 mA; +24 V, 100 mA; -24 V, 105 mA.

### Weight

**Net** 1.5 kg (3.3 lb.)

**Shipping** 3.1 kg (7.0 lb.)

**Dimensions** Standard single-width NIM module 3.43 x 22.13 cm (1.35 x 8.714 in.) per DOE/ER-0457T.

### CONTROLS

**FINE GAIN** 10-turn precision potentiometer with graduated dial for continuously variable direct-reading gain factor of X0.5 to X1.5.

**COARSE GAIN** 6-position switch selects feedback resistors for gain factors of 20, 50, 100, 200, 500, and 1k. Jumper on the printed wiring board (PWB) selects X0.1 attenuation.

**INPUT** Locking toggle switch selects either Pos or Neg input pulse



polarity.

**SHAPING TIME** 6-position switch selects time constants for active pulse-shaping filter network from 0.5, 1, 2, 3, 6, and 10  $\mu$ s.

**PZ ADJ** Screwdriver adjustable potentiometer to set the pole-zero cancellation to compensate input decay times from 40  $\mu$ s to infinity.

**BLR** 3-position locking toggle switch selects the source of control for the gated baseline restorer discriminator threshold from:

**Auto** The BLR threshold is automatically set to an optimum level, as a function of the signal noise, by an internal circuit.

**PZ Adj** The BLR threshold is determined by the threshold potentiometer. The BLR time constant is also greatly increased to facilitate pz adjustment; this position may give the lowest noise for count rates under 5000 counts/s and/or longer shaping times.

**Threshold** The BLR threshold is manually set by the threshold potentiometer.

**DC** Screwdriver adjustable potentiometer to set the Unipolar Output dc level; range  $\pm 100$  mV

### INPUTS

BNC front- and rear-panel connectors accept either positive or negative pulses with rise times of 10 to 650 ns and decay times of 40  $\mu$ s to infinity,  $Z_{in} \cong 1000 \Omega$  dc-coupled; linear maximum 10 V; absolute maximum 20 V.

### OUTPUTS

**UNI** Front-panel BNC connector with  $Z_o < 1 \Omega$  and rear-panel connector with  $Z_o = 93 \Omega$ , short-circuit proof; with full-scale linear range of 0 to +10 V; active filter shaped; dc-restored; dc-level adjustable to  $\pm 100$  mV.

**BI** Front-panel BNC connector with  $Z_o < 1 \Omega$  and rear-panel connector with  $Z_o = 93 \Omega$ , short circuit proof; prompt output with positive lobe leading and linear range of  $\pm 10$  V; active filter shaped.

**CRM** Rear-panel BNC connector with  $Z_o < 10 \Omega$  provides a nominally +5 V, 300 ns logic pulse every time the input signal exceeds the baseline restorer discriminator threshold.

**INH** Rear-panel BNC connector with  $Z_o < 10 \Omega$  provides a nominally +5 V logic pulse (width equal to 6X shaping time) when the internal pile-up rejection logic detects a distortion of the input signal due to pile-up.

**BUSY** Rear-panel BNC connector with  $Z_o < 10 \Omega$  provides a +5 V logic pulse for the duration that the input pulse exceeds the baseline restorer discriminator.

**PREAMP POWER** Rear-panel standard ORTEC power connector. Amphenol 17-10090, mates with captive and noncaptive power cords on all ORTEC preamplifiers.

**Preamplifier Power** Rear-panel standard ORTEC power connector, Amphenol 17-10090.

### ORDERING INFORMATION

<b>Model</b>	<b>Description</b>
572A	Amplifier

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## 575A Amplifier Specifications

### PERFORMANCE

**Gain Range** Continuously adjustable from 5 to 1250.

**Pulse Shape** Semi-Gaussian on all ranges with peaking time equal to  $2.2\tau$ , 50% pulse width equal to  $3.3\tau$ , and pulse width at 0.1% level equal to 4.0 times the peaking time. Bipolar crossover =  $1.5\tau$

**Integral Nonlinearity** For 1.5- $\mu$ s shaping time,  $<\pm 0.05\%$ .

**Noise**  $<5\ \mu$ V rms referred to the input using 3- $\mu$ s unipolar shaping;  $<7\ \mu$ V using 1.5- $\mu$ s shaping; both for a gain  $\times 100$ .

### Temperature Instability

**Gain**  $\pm 0.0075\%/^{\circ}\text{C}$ , 0 to  $50^{\circ}\text{C}$ .

**DC Level**  $\pm 30\ \mu\text{V}/^{\circ}\text{C}$ , 0 to  $50^{\circ}\text{C}$ .

**Bipolar Crossover Walk**  $\pm 5\ \text{ns}$  at 0.5  $\mu$ s for 50:1 dynamic range, including contribution of an ORTEC Model 552 Single-Channel Analyzer.

**Overload Recovery** Recovers to within 2% of rated output from X300 overload in 2.5 nonoverloaded pulse widths using maximum gain for unipolar output. Same recovery from X500 overload for bipolar.

**Restorer** Gated active baseline stabilizer with automatic threshold circuit to provide the threshold level as a function of signal noise to the baseline restorer discriminator.

**Spectrum Broadening** Typically  $<10\%$  FWHM for a  $^{60}\text{Co}$  1.33-MeV gamma line at 85% of full scale for an incoming count rate of 1,000 to 50,000 counts/s (Unipolar output, 1.5- $\mu$ s shaping).

**Spectrum Shift\*** Peak position shifts typically  $<0.02\%$  for a  $^{60}\text{Co}$  1.33-MeV gamma line at 85% of full scale measured from 1,000 to 50,000 counts/s (Unipolar output, 1.5- $\mu$ s shaping).

\*These count-rate specifications were measured with a 10% HPGe detector. Detectors with a large number of slow rise-time signals will most likely give poorer results.

### ELECTRICAL AND MECHANICAL

**Power Required** +12 V, 55 mA; -24 V, 40 mA; +12 V, 70 mA; -12 V, 75 mA.

### Weight

**Net** 1.5 kg (3.3 lb.)

**Shipping** 3.1 kg (7.0 lb.)

**Dimensions** Standard single-width NIM module 3.43 x 22.13 cm (1.35 x 8.714 in.) per DOE/ER-0457T.

### CONTROLS

**FINE GAIN** 10-turn precision potentiometer with graduated dial for

continuously variable direct-reading gain factor of X2.5 to X12.5.

**COARSE GAIN** 6-position switch selects feedback resistors for gain factors of 2, 4, 10, 20, 40, and 100.

**SHAPING TIME** 3-position printed wiring board (PWB) jumpers, easily accessible through side panel, select time constants for active pulse-shaping filter network from 0.5, 1.5, and 3  $\mu$ s.

**POS/NEG** Toggle switch selects either Pos or Neg input pulse polarity.

**PZ ADJ** Screwdriver adjustable potentiometer to set the pole-zero cancellation to compensate input decay times from 30  $\mu$ s to infinity.

### INPUTS

BNC front- and rear-panel connectors accept either positive or negative pulses with rise times of 10 to 650 ns and decay times of 30  $\mu$ s to infinity,  $Z_{in} \cong 1000 \Omega$  dc-coupled; linear maximum 2 V; absolute maximum 20 V.

### OUTPUTS

**UNI** Front-panel BNC connector with  $Z_o < 1 \Omega$  and rear-panel connector with  $Z_o = 93 \Omega$ , short-circuit proof; full-scale linear range of 0 to +10 V; active filter shaped; dc-restored; dc-level adjustable to  $\pm 15$  mV.

**BI** Front-panel BNC connector with  $Z_o < 1 \Omega$  and rear-panel connector with  $Z_o = 93 \Omega$ , short circuit proof; positive lobe leading and full-scale linear range of 0 to +10 V; active filter shaped.

**PREAMP POWER** Rear-panel standard ORTEC power connector. Amphenol 17-10090, mates with captive and noncaptive power cords on all ORTEC preamplifiers

### ORDERING INFORMATION

Model	Description
575A	Amplifier

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# LAB 5: Speed Measurement by Optical Techniques

J.-C. Diels and W. Rudolph

## Purpose:

Familiarize the student with the Doppler effect as used for speed measurement, spatial filtering, spectrum analyzers, and interferometric techniques.

## Reading Assignment

As referenced in text, and Chapter 4 of *Building Scientific Apparatus*, 3rd edition, by John Moore et al. (Perseus Books, Cambridge MA, 2003).

## Introduction

The most obvious optical method for measuring the speed of a moving object is to use the Doppler effect: light reflected from the moving object will be shifted in frequency in proportion to the line of sight velocity of the object. While we are familiar with examples in the radio domain (such as police traffic radar and Doppler weather radar) and with acoustic waves (the apparent change in pitch of a passing siren), demonstrating the Doppler effect optically is not a trivial matter. The primary reasons for this are:

1. Optical frequencies are much too high ( $\sim 10^{14}$  Hz) to be measured directly, and
2. The shift corresponding to typical speeds is on the order of 0.1 - 10 MHz, much less than the line width of a typical He-Ne laser.

It is nonetheless possible to demonstrate the Doppler effect interferometrically using simple equipment. In this experiment, you will use a small He-Ne laser, an electronic spectrum analyzer, a photodiode detector, and some simple optical elements to measure the shift in frequency of light scattered from the back of a small moving train, a rotating disk, and from particles suspended in flowing water. From this information you will be able to determine the velocity profile of the water flowing through a tube, the speed of a train, the speed of a disk, and (after directly measuring the disk speed) the wavelength of the laser.

One disadvantage of the Doppler effect to measure speed is that you can only determine the velocity component along the line of sight. It is possible to measure the transverse speed optically in spite of this handicap, again interferometrically. The trick is to project first an interference pattern onto the object, then measure the frequency of the light fluctuations as it passes through the fringes. The fringe spacing is determined from the geometry of the experimental setup, and the speed is then given by the product of this spacing and the characteristic frequency of the scattered light fluctuations. For this part of the experiment a rotating disk will again be used, although a much faster rotation rate is required for the effect to be readily observable.

## Theory and Concepts

At this point the question arises “How do we get around the problems mentioned in the introduction?” The answer is a technique known as *heterodyne interferometry*. This method involves combining the frequency-shifted or modulated optical (or radio, microwave, etc.) signal with an unshifted reference signal. The so-called “square-law” detector (which includes all common optical detectors) will respond only to the intensity (and intensity variation) of the combined beam. If the frequencies of the two signals differ by less than the bandwidth of the detector and are not identical, the electrical output of the detector will be modulated at a frequency equal to the difference between the frequencies of the two beams. For simplicity let us assume two electromagnetic waves of equal amplitude  $A$  and frequencies  $\omega_1$  and  $\omega_2$ . If the two waves are incident on a detector we measure a signal

$$S = \langle (A\cos\omega_1 t + A\cos\omega_2 t)^2 \rangle \quad (2.1)$$

where  $\langle \rangle$  denotes averaging performed by the detector and subsequent electronics. Using the identity  $2\cos\omega_1 t \cos\omega_2 t = \cos(\omega_1 - \omega_2)t + \cos(\omega_1 + \omega_2)t$  we can write the signal as

$$S = A^2 \langle \cos^2 \omega_1 t \rangle + A^2 \langle \cos^2 \omega_2 t \rangle + A^2 \langle \cos(\omega_1 - \omega_2)t \rangle + A^2 \langle \cos(\omega_1 + \omega_2)t \rangle \quad (2.2)$$

Typically, in particular if we work with light, the frequencies  $\omega_{1,2}$  cannot be resolved directly and the detection system averages the terms 1, 2, and 4 in Eq. (2.2). The time dependence of the signal (the 3<sup>rd</sup> term in (2.2)) is then characterized by a frequency

$$\omega_{beat} = |\omega_1 - \omega_2|$$

This modulation is also referred to as a *beat frequency* or a *beat note* after the analogous acoustic phenomenon.<sup>†</sup> When two nearly identical tones are played together, the result is a ‘waa-waa-waa’ variation of the loudness with a periodicity equal to the inverse of the frequency difference of the two tones.

So the heterodyne technique eliminates problem 1 above, as long as the Doppler shift is not too large. But what of problem 2? The stability of a small He-Ne laser, over a time span of a few seconds, is certainly no better than a several MHz. Thus you should not be able to measure speeds  $< 2 \text{ m/s} \sim 10 \text{ km/hr}$ , right? Wrong, as can be seen by comparing the coherence time of such a laser (tens of ns), the time delay between the signal and reference beams for the experimental arrangements used here ( $< 1 \text{ ns}$ ), and the Schawlow-Townes linewidth of a laser ( $\sim$  Hertz). Qualitatively, what **would** be the limit of such a measurement? (Note: It is worth devoting a few lines to this in your report.)

The theory of the Doppler effect is covered in most basic physics texts, and will not be discussed here. The arrangement in the first part of this experiment is identical to a Michelson interferometer, and the expected frequency shift of the light can be derived by considering the object to be equivalent to the translating mirror. From this point of view, the beat note signal is just the rate at which fringes pass the detector. In the second (fast wheel) part, the measured frequency is the quotient of the transverse speed of the wheel and the fringe spacing, which is determined by the wavelength of the light used and the angle of intersection of the two beams. For the third (water flow) part of the experiment, the angle of intersection of the

beams and the refractive index of water must be taken into consideration. The necessary derivations are left to the student and a summary thereof should be included in the lab write-up.

All three parts of this experiment involve measuring the light scattered from a large number of randomly placed scattering centers. Given that the characteristic frequency of interest is the same for all of the scatterers, the signal from each will be randomly phased so one might expect any modulation at that frequency to average out. Furthermore, since the collected light is due to scattering, the total intensity can vary wildly at frequencies unrelated to the one in which we are interested. Considering such a small signal to noise ratio, how can we expect to measure anything? (Hint: The net signal from an ensemble of randomly phased sources is a problem analogous to the drunkard's walk. Also, the beauty of using spectrum analysis is that it measures the total amplitude of signals over only a small range of frequencies. Thus the appropriate figure of merit is the ratio  $S/N$  where  $S$  is the signal amplitude at a frequency of interest and  $N$  is the amplitude of the noises whose frequencies are within one resolution bandwidth of the signal .

### Experimental Procedures

This experiment is divided into three parts: a) Doppler shift measurement of the speed of a train and a rotating wheel; b) Transverse velocity measurement of the speed of a different wheel using scattering from a fringe pattern; c) Doppler shift measurement of the velocity profile of water flowing through a tube.

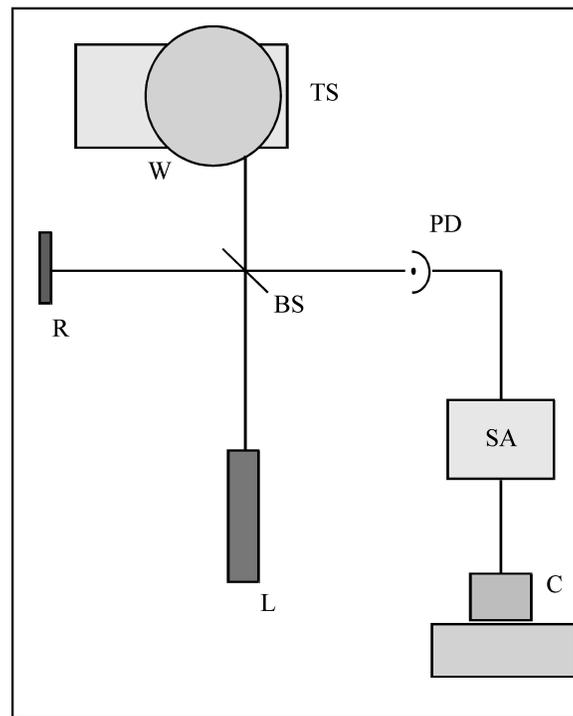


Figure 1. Experimental setup for the slow wheel Doppler Shift measurements.  $L$  is the laser source,  $BS$  is a beam splitter,  $W$  is a motor driven wheel with reflective tape on its rim,  $R$  is a reflector (also tape covered), and  $PD$  is the optical detector. The electrical signal is sent to the 3585A spectrum analyzer  $SA$  for analysis and then to the computer  $C$  for recording. The translation stage  $TS$  is provided for positioning the wheel.

*Doppler shift from a train and a rotating wheel.* The experimental setup for the wheel is sketched in Fig. 1. Note the equivalence of this arrangement to a Michelson interferometer. The beam from laser  $L$  is split by beam splitter  $BS$  and directed onto the edge of the slowly rotating wheel  $W$  and reference reflector  $R$ , both of which are covered with retroreflecting tape (of the type used by runners, bicyclists, etc., to avoid getting hit by cars). This tape is composed of small beads embedded in a substrate with a matched refractive index such that light entering the bead is refracted to the back of the bead where it is internally reflected back toward the source. This eliminates the need for the precise alignment required when flat mirrors are used. The retroreflected beams are then recombined at the beamsplitter and continue to detector  $PD$ . The electrical signal from  $PD$  is sent to a spectrum analyzer  $SA$  for measurement.

A spectrum analyzer (HP 3585A) is used to measure the beat frequency may be measured directly. You can transfer the spectra to a computer - see Appendix for instructions. First, calculate the expected Doppler shift from an estimate of the wheel rotation rate and set the analyzer accordingly. Before connecting the detector signal to the spectrum analyzer, look at it with an oscilloscope; what is the amplitude of the signal, and does its period correspond to your calculated estimate? Measurements are to be made over a range of wheel positions at roughly one centimeter intervals, for which translation stage  $TS$  is provided. The range chosen should be such that one edge is accessible. Note: You must be sure that you are looking at the right peak on the spectrum analyzer trace. Determine this by blocking either the reference or shifted beams (the signal will then disappear) and by translating the wheel (the signal frequency should then shift). Once the data are taken, you will also need the diameter of the wheel, a direct measurement of its rotation rate, and the wavelength of the laser. From these you should be able to determine the rotation rate of the wheel and to estimate the precision of your measurements. Discuss the precision of your results and the important error sources.

*Transverse speed measurement.* As pointed out earlier, the Doppler technique is applicable only for measuring longitudinal velocities. (There is in fact a transverse Doppler effect, but it goes as  $v^2/c^2$  and so is observable only for relativistic particles.) However, it is possible to measure the transverse velocity of an object using light scattering. The setup is as shown in Fig. 2. The laser beam is split and reflected by  $BS$  and mirror  $M$  onto the edge of the fast rotating wheel  $W$ , intersecting at its surface at an angle  $\alpha$  to form a fringe pattern of spacing  $\delta L$ . This spacing should be too small to be visible with the unaided eye but much greater than the wavelength of light (i.e., between 5 and 50  $\mu\text{m}$ ). As it is determined by the beam crossing angle  $\alpha$ , you must position  $BS$  and  $M$  appropriately. The most accurate way to find this angle is to measure the separation of the beams some distance from their intersection; take several such measurements at different positions to obtain an accurate value for  $\alpha$ .

The scattered light may be viewed from the side, as shown in Fig. 2. A lens  $L$  is used to collect the scattered light and focus it onto the detector  $PD$ . As before, the detector signal is sent to the spectrum analyzer. The signal frequency of interest may be discerned by blocking either of the interfering beams - it should disappear. Position the wheel transversely to maximize the scattering frequency (i.e., so that the scattering comes from the foremost point on the wheel). Adjust the spectrum analyzer to fully resolve the signal frequency and measure its value. Also measure the diameter of the wheel and estimate its rotation rate observing the detector signal on an oscilloscope - though it may be quite noisy, it should be periodic over one rotation.

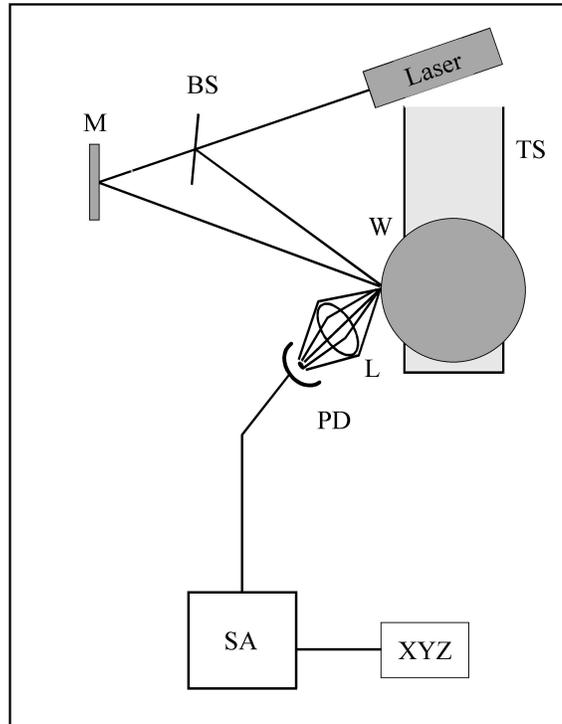


Figure 2. Experimental setup for the transverse speed measurements. Most labeled parts are as in Fig. 1, except that  $L$  is a collecting lens (optional)  $M$  is a flat mirror, and  $XYZ$  is a PC to which the spectra can be transferred.}

Report the measured frequency and its bandwidth. Calculate  $\alpha$  and  $\delta L$ , and the rotation rate. How does this compare with the oscilloscope estimate? Which would you expect to be more accurate and why? What are the major sources of error in this experiment, and in particular what is the effect of the bandwidth of the measured scattering frequency?

*Velocity profile of flowing water.* This is probably the most difficult part of the experiment. It is diagrammed in Fig. 3. A small portion of the laser beam is split off by the microscope slide  $BS$  (reflectance  $\sim 4\text{-}5\%$  per face). This reference beam is directed through the flow tube  $FT$  perpendicular to its faces and through aperture  $A$  and lens  $L$  onto detector  $PD$ . The rest of the laser beam is reflected at mirror  $M$  to intersect the reference beam at a point inside  $FT$ , at an angle of  $10^\circ - 35^\circ$ . (This angle is measured as in the transverse velocity measurements above - but be sure to account for the differing indices of water and air.) The tube is filled with water in which a colloidal substance has been suspended - CoffeeMate nondairy creamer works nicely - and is connected to a pump. The suspended particles serve to scatter some of the strong signal beam into the detector where it will be mixed with the reference, any frequency shift will then be observable with the spectrum analyzer. Note the similarity of this arrangement to a Mach-Zehnder interferometer. We should expect the signal beam to be Doppler shifted by an amount determined by the projection of the flow velocity onto the direction of the signal beam (the derivation of the expected shift is left to the student).

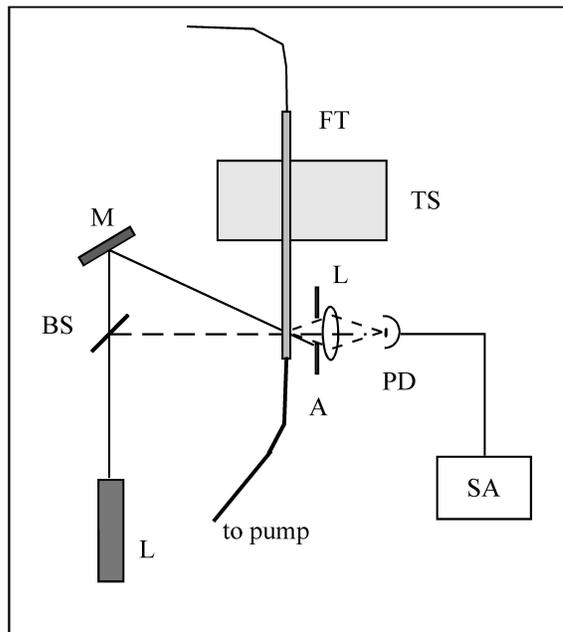


Figure 3. Experimental setup for the flow profile measurements. *BS* is a microscope slide, *FT* is the flow tube, and *A* is an aperture.

Several important factors must be considered for this experiment to work properly. First, it is essential that the flow be laminar - a turbulent flow will give Doppler shifts over a wide range of frequencies, blurring the spectrum analyzer peak until it becomes unrecognizable. Second, we must limit the size of the particular scattering region at which we are looking for each measurement - if the volume is large, there will again be a range of frequencies in the spectrum. This is the function of the lens: it images a small region within the intersection volume onto the detector. Third, we must restrict the range of scattered wave vectors - light scattered off at different angles will have different Doppler shifts, again broadening the frequency peak. This is the function of the aperture *A*: although the lens will image any light scattered from the volume of interest onto the detector, the aperture blocks all but that light propagating along the direction of the reference beam. (A vertical slit could be used instead. Why?)

Special care must be taken to obtain a signal which is sufficiently clean for taking measurements. The detector should be placed so that it receives the reference beam directly. The position of the lens is particularly critical. Initially determine the approximate height and transverse position by centering the lens on the reference. Then find the longitudinal position in the following manner: Translate the tube so that the beams intersect at the face nearest the detector. Block the beams with a thin sheet of paper and adjust the positions of *L* and *PD* to image the beam-spot onto the detector element. Then remove the paper and check that the reference beam is not deflected away from the detector - if it is, repeat the positioning steps. When this procedure is completed, translate the flow tube *FT* so that the beam intersection is in the middle of the tube. Adjust the spectrum analyzer until a signal is found (start by estimating the expected Doppler shift). The true beat note signal will disappear when either of the beams is blocked. Check to see that the frequency varies with the pump speed. When you have found the beat note, adjust the position of the various components to maximize the signal amplitude. If the signal is sufficiently above the background ( $> 10$  dB), you will be able to take the necessary data by computer as with the slow wheel. Take measurements at  $\sim 1$  mm intervals starting at one side and continuing until the other side is reached. In analyzing your data, plot the profile and qualitatively compare

it with what would be expected for a laminar flow (look it up). As usual discuss experimental problems, error sources, etc. Note: On occasion this experiment does not work out very well. If such is the case for you, at least obtain a measurement of the speed at the center of the tube and explain the problems encountered.

### **Summary of Procedures**

Upon completion of this experiment you should have sufficient data to obtain the following:

- The rotation rate of the slow wheel using the Doppler effect.
- The speed of the toy train (compare with direct measurement).
- The rotation rate of the fast wheel using the interference-scattering technique.
- The velocity profile of a laminar flow, via the Doppler effect. \end{itemize}.

### ***Food for thought***

Doppler velocity with the Michelson arrangement. It is not really necessary to invoke the Doppler Effect. Find an alternate explanation (it should lead to the same numerical expression)

Transverse velocimetry measurement (fast wheel). This can be interpreted also through the Doppler effect...

### **REFERENCES**

1. M. V. Klein and T. E. Furtak, *Optics* (Wiley, New York, 1986).

## APPENDIX: HP 3585A Spectrum Analyzer

The Hewlett-Packard 3585A is a digital spectrum analyzer with a bandwidth of 20 Hz - 40 MHz. It can be operated manually by the front panel controls, or by computer via the IEEE-488 interface. The manual method is the subject of this appendix.

The entry keys of the front panel are divided into eight groups: INPUT, ENTRY, SWEEP, TRACE, MARKER/CONTINUOUS ENTRY, RBW-VBW-ST, STATUS, and TRIGGER. The pertinent keys in each of these groups will be discussed below. Most keys are designed so that they will be lit, or a corresponding entry on the CRT display highlighted, when on or in effect.

Before discussing the key panel, look at the CRT display. The horizontal axis is in units of frequency, and either the START and STOP frequencies or the CENTER frequency and frequency SPAN will be given below the bottom grid line. The vertical scale gives the power of the signal in logarithmic units (dBm, dBV, or dB) with the power corresponding to the top grid line given by REF, the values for the other lines decreasing from this value by the amount given in dB/DIV, both displayed in the upper left corner. (Remember that a signal ratio of 10 dB implies an electrical power ratio of 10, while a ratio of 20 dB implies a voltage ratio of 10. For most optical detectors, it is the output voltage that is proportional to the optical power in.) The RANGE determines the noise level due to the internal amplifiers. The upper right corner usually gives the MARKER position, but may display other information, and will be discussed later. The meaning of the entries on the bottom line will likewise be discussed below. The CRT is also used to display various messages, which will generally be accompanied by a warning tone. For example, every two minutes or so the instrument will execute a self-calibration routine and "CALIBRATING" will briefly appear on the screen; similarly, if front panel operation is attempted while the device is in the remote mode, the message "HP-IB OPERATION ONLY" will be displayed.

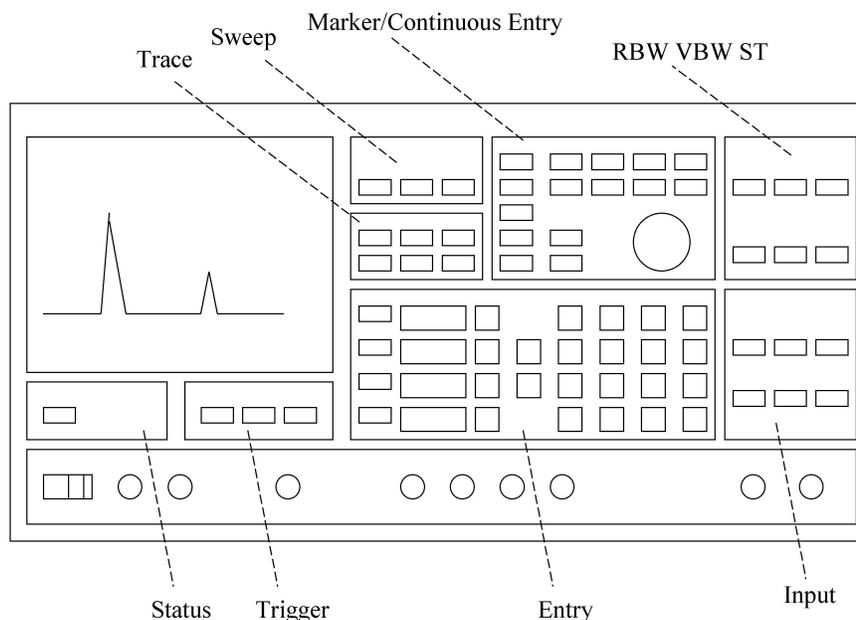


Figure 1. Layout of the HP 3585A Spectrum Analyzer front panel

## The Eight Panel Groups

1. *INPUT*. Proper settings and connections of the INPUT group are required to obtain a trace, and to prevent overloading. For low frequency applications, the IMPEDANCE should be set to  $1\sim M\Omega$ ; the  $50\ \Omega$  and  $75\ \Omega$  inputs need to be used only when investigating frequencies of  $>10$  MHz and when the source is capable of driving such an impedance. The signal source must be connected to the input jack corresponding to the active IMPEDANCE setting. When AUTORANGE is on, the input amplifier RANGE will be adjusted to suit the input signal; with REF LEV TRACK on the power level corresponding to the top of the display grid will follow any adjustments of the RANGE (whether this is due to AUTORANGE, or to any manual STEP KEY or numerical entry)
2. *ENTRY*. This group is the most important of the eight. In particular, the REFERENCE LEVEL, dB/DIV, START FREQ/STOP FREQ and/or CENTER FREQUENCY/FREQUENCY SPAN may be set using the STEP, numerical, and unit keys. To change the value of any of these parameters, press the corresponding key. The corresponding CRT entry will then be highlighted, and the value may be changed either incrementally using the STEP keys (which usually change the parameter by a factor of 2 or in a 1-2-5-10 or 1-3-10 sequence) or by numerical entry from the keypad. If the new value is not allowed a bell will sound and possibly an error message will be displayed; the parameter will remain highlighted awaiting an acceptable entry. A change implemented by the STEP keys will be effected immediately, while a numerical entry will not take effect until an appropriate unit is entered. In either case, the CRT entry will remain highlighted until a units key has been pressed.
3. *SWEEP*. The SWEEP (i.e., the scanning of the internal reference oscillator through the appropriate range of frequencies) may be either CONTINUOUS (a new sweep beginning as soon as the last one is completed) or SINGLE (sweeping stops when the STOP FREQ is reached). In either case the SWEEPING light will be lit and the CRT trace will be continually updated while the sweep is in progress. The MANUAL ENTRY mode is rarely useful.
4. *TRACE*. The 3585A can store two traces: A, which is continually updated during sweeping, and B, which can be used for permanent storage. A trace must first be obtained in the A trace, then it can be transferred to B by pressing the STORE A $\rightarrow$ B key. Either or both can be viewed at any time, as can their algebraic difference A - B, by activating the appropriate key. The B trace is particularly useful for storing a good trace for later plotting, or for storing baseline noise trace which can then be subtracted from the A signal trace.
5. *MARKER/CONTINUOUS ENTRY*. The MARKER is the highlighted pixel on the spectrum trace which can be positioned by the CONTINUOUS ENTRY knob. The frequency and signal amplitude at its position on the trace will be given in the upper right corner of the CRT when it is active. When the COUNTER feature is active the trace will stop for  $\approx 0.1$  s when the marker frequency is reached and the device will measure the frequency (to an accuracy of 0.1 Hz) of the strongest signal within one resolution bandwidth (RBW - see below) of the marker frequency. The other features in this group are of little interest for our purposes.
6. *RBW-VBW-ST*. The RESolution Bandwidth is the frequency range allowed through the input filters to the system amplifiers, it is thus the displayed width of any input signal of bandwidth less than the RBW value displayed at the lower left corner of the CRT. It can be reduced to

resolve closely spaced signal or increased to speed up the sweep rate if the extra resolution is not needed. The VIDEO BandWidth (VBW - bottom center of the CRT) is, qualitatively speaking, the inverse of the time over which a particular element of the display is average; as such, it can be reduced to average fluctuations in the noise level which might mask weak signals, or increased to reduce the SWEEP TIME. With the COUPLES TO SPAN feature active, the SWEEP TIME (ST - lower right corner of the display) will be automatically set to the minimum value for which the instrument can still take calibrated measurements; if the ST is too small for the RBW and VBW, the UNCAL LED will light, and the SWEEP TIME increased until it goes off. The RBW and VBW can be varied in a 1-3-10 sequence only; the ST can be set to any multiple of 0.2 s.

7. *STATUS*. When the 3585A is being controlled via the IEEE-488 [also know as the HP-IB (Hewlett-Packard Interface Bus) and GPIB (General Purpose Interface Bus)] interface on the rear of the instrument, the REMOTE LED will be lit and the front panel will be disabled. The other three LEDs indicate the status of the instrument with respect to the bus. REMOTE control may be overridden and front panel operation restored by pressing the local key.

8. *TRIGGER*. The FREE RUN mode should be used.

*Plotting*. Though not an entry key group, the capability to generate a hard copy plot of the displayed frequency spectrum is a useful feature of the 3585A. To obtain a plot, an X-Y recorder must be connected to the X and Y PLOTTER OUTPUT connectors on the back panel of the instrument (if the recorder provides a remote pen lift feature, this should be connected to the Z output - note however that there may be some compatibility problems). The plot is initiated by pressing the RECALL (on) key [lower left corner of the ENTRY block] then the 8 (plot1) key. An analog copy of the trace will be sent to the output jacks at a rate which a typical recorder will be able to follow. Output voltages will range from 0 V (START FREQUENCY) to +10 V (STOP FREQUENCY) for X, and from 0 V (lower grid line) to +10.64 (REFERENCE LEVEL = 10.4 V) for Y. Set the recorder inputs ranges accordingly. The outputs are set to the high limits after each plot, so zero the recorder at the upper right corner of the page.

*A simple demonstration - "Watching the radio"*. To demonstrate the operation of the 3585A, connect a short piece of unshielded cable to the 1M $\Omega$  input. Tune the START and STOP frequencies to locate the AM radio band (0.5 - 1.6 MHz). Position the marker on one of the stations and measure the frequency of the station using the COUNTER. Watch the frequency and amplitude of the signal over several measurements. Can you see why these are 'amplitude modulation' stations rather than 'frequency modulation'? Can you find the FM stations?

As mentioned in the former subsection, the Hewlett-Packard 3585A spectrum analyzer may be remotely operated by computer via the IEEE-488 interface [also known as the HP-IB (Hewlett-Packard Interface Bus, or GPIB (General Purpose Interface Bus)]. The program DOPPLER.EXE has been written to drive the 3585A and to collect the appropriate data for this experiment. Use of this program is the subject of this portion. Throughout this section anything that is enclosed in quotes " " is what you will be expected to type from the keyboard; names of special keys which you must type will be enclosed in Dirac brackets (e.g., <esc>, <enter>, etc.).

*Setting up.* Turn on the computer, and the 3585A. Get into the optics lab directory by typing "CD/OPTLAB<enter>". Obtain a signal trace on the analyzer and move the marker to the top of the peak. Once this is done you are ready to initiate the program by typing "DOPPLER<enter>".

*Initializing the program.* The program will begin by displaying a summary of its operation, which will remain on screen until you press <enter>. The screen will then be cleared and you will be asked for the name of a file in which to store your data. Enter this as a root name of up to eight letters followed by a period followed by a three letter suffix (#####.###, e.g., MYDATA.NEW or GEORGE.DAT). The computer will then take control of the 3585A and take a datum as an operational test; so long as the system does not hang up and no bells are sounded, everything is OK. You will then be asked to type ``T<enter>" when you are ready to begin data taking or ``A<enter>" if for some reason you wish to abort the program.

*Data collection.* You will next be prompted for the initial position reading of the translation stage. Enter this in centimeters or millimeters, but always be consistent - use one or the other throughout the session. The computer will then turn the 3585A COUNTER feature on, trigger a trace, wait for the analyzer to measure the frequency, then request the value of the measurement. It will then display (on the computer CRT) the number of data points taken thus far, the current position of the translation stage, and the current frequency measurement. It will also move the spectrum analyzer MARKER to the measured frequency so that you can determine whether the counted frequency corresponds to the Doppler shift signal. You will then be asked whether to keep the datum or reject it. The datum should be rejected if the reported does not correspond to the reading from the translation stage (in which case you moved to the peak of the Doppler shift signal (in which case you should move the MARKER manually to that position using the CONTINUOUS ENTRY knob on the 3585A front panel - this will prepare the instrument for the next measurement). After keeping/discarding the datum you will be prompted with "Type <enter> to continue, <space><enter> to change position, or STOP to quit". Respond accordingly. If the first option is chosen, a new trace will be triggered and a new measurement taken. If you want to 'change position' you will be prompted for the new position; move the translator, type in the new reading, and press <enter> to indicate a new measurement. Respond with "STOP" if you are finished taking data or if you wish to quit the session; the output data file will be closed and the 3585A will be returned to manual control.

*Suggestions.* You will want to take several data points at each position to get an idea of the accuracy of your measurements. Also, you may need to change the CENTER/SPAN or START/STOP frequencies to keep the signal on the trace. Similarly, the RBW, VBW, and dB/DIV may need to be adjusted to suit the signal. If you have problems with spurious signals, the A-B feature is very useful.

# LAB 6: The Wavemeter

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## Purpose:

Familiarize the student with the Michelson interferometer, gaussian beams and the transformation of gaussian beams by lenses.

## Reading Assignment

As referenced in text, and Chapter 4 of *Building Scientific Apparatus*, 3rd edition, by John Moore et al. (Perseus Books, Cambridge MA, 2003).

## Background

The goal of this experiment is to utilize the sensitivity of the Michelson interferometer, used here in a wavemeter, to precisely determine the frequency and wavelength of an “unknown” laser. Due to the wavelike nature of light, the basic Michelson interferometer, as depicted in Fig.1, produces dark and bright fringes at the photodetector (PD) as the length of one arm is continuously varied by an amount  $\Delta$ . These fringes are the result of constructive and destructive interference of the fields from each arm of the interferometer. For a more detailed description of the Michelson interferometer, see Hecht.

## Theory

The intensity at the output of a Michelson interferometer, see Fig.1, that is recorded by the photodiode is given by:

$$I = (I_0/2) [1 + \cos\{2\pi(d_2 - d_1)/\lambda\}]$$

The photodetector will see one fringe go by for a displacement of one half wavelength of  $M_1$ . If we translate  $M_1$  by a known distance  $d$ , and count the number of fringes  $N$  on the photodetector, we can then determine  $\lambda$  from the relationship

$$d = N\lambda/2$$

by measuring  $N$  and  $d$ . If for instance  $d = 30$  cm and  $N = 10^6$  fringes, then  $\lambda = 0.6$   $\mu\text{m}$ . There are, however, two limiting factors on the precision with which we can determine  $\lambda$ . 1) How well we know  $N$ , and 2) how accurately we can determine  $d$ . For instance, even if  $d$  is known with absolute accuracy, simple fringe counting would only yield an accuracy of  $10^{-6}$  for the determination of the wavelength, limited by the lack of information from rounding off to the nearest fringe integer. A higher precision is possible by recording the interference fringes and calculating the position between fringes after the last full fringe has been counted, such that  $N$  is known to a certain number of decimal places.  $N$  is in fact the round-off of  $\arccos(2I/I_0)$ :

$$N = \text{INT} [\arccos(2I/I_0) - 1/2]$$

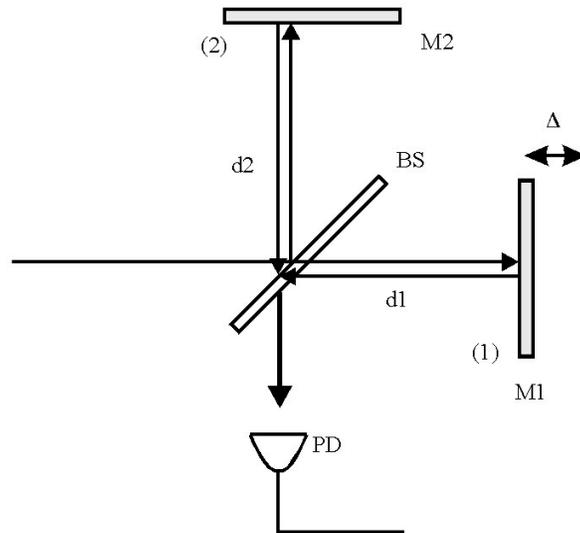


Figure 1. Michelson Interferometer

Determining  $N$  with a higher precision will help, but in reality the distance  $d$  cannot be measured with the required accuracy. One could try to translate  $M_1$  uniformly and to record accurately the fringe count rate. Knowing the speed of translation, one could determine the wavelength from the fringe counting rate (or frequency). The problem with that approach is in achieving the required uniformity of motion. One could use synchronous motors (the frequency stability of the 60 Hz network is fairly good). However, the error in the reducing gears and lead screw of the translation stage make it impossible to achieve uniform translation speed. In fact, a chart recording of the fringes of an interferometer using a synchronous motor driven translation stage will indicate periodic changes in “wavelength”, which can be used to identify the gear sizes and defects in the reduction box. Therefore, a simple way to determine the quality of such a drive mechanism is to record closely spaced fringes (chart the motor on a low speed relative to the periodicity of the interferences), and copy them on a transparency. The “Moire” pattern observed when the transparency is superimposed on the original recording is an indication of the speed variations in the motor drive.

So how then can we determine  $d$  with the required precision? The answer seems almost circular: use the laser. It is usually the frequency of a laser which is known with the most precision. The absolute frequency of many well stabilized lasers has been determined by beating its frequency down, in a long chain of complicated nonlinear mixing devices, to a range in which it can be compared with the current definition of time, the ground state hyperfine splitting of cesium, which is 9 192 631 770 Hz. As of 1983, the speed of light has been *defined* to be 299 792 458 m/s. Thus by knowing the precise frequency of the laser, and using the defined value for the speed of light to determine the wavelength (in vacuum), one can calculate the distance  $d$  from the equation for  $\lambda$  above. This is in fact how the meter is currently defined, through the definition of  $c$  and the second. This technique will then require two lasers, the frequency of one of them is well known. *The fringe count of the known laser frequency is used to calculate the distance  $d$ , which is in turn used - knowing the fringe count for the other laser - to calculate the unknown*

wavelength. Several arrangements are possible. One of them is the Mach-Zehnder interferometer. The other is the double Michelson sketched in Fig. 2.

One should be aware that this method provides a wavelength ratio in the laboratory environment. Depending on how successful your experiment is, you may have to correct for the dispersion of air. The appropriate constants for that correction can be found in the *Handbook of Chemistry and Physics* (Chemical Rubber Co.)

Two other limitations are the bandwidth and stability of the reference laser, as well as that of the laser to be measured. These (bandwidth and stability) are two different factors, which might - but need not - be related.

### Experimental Setup

Attempt to make a Michelson interferometer using an air rail as one arm, see Fig. 2. This interferometer will be used as a wavemeter by combining two lasers, a known reference (red He-Ne) and an unknown source (green He-Ne, this is the least you should determine!). The polarization of the lasers should be orthogonal to each other. Using a polarizing beamsplitter

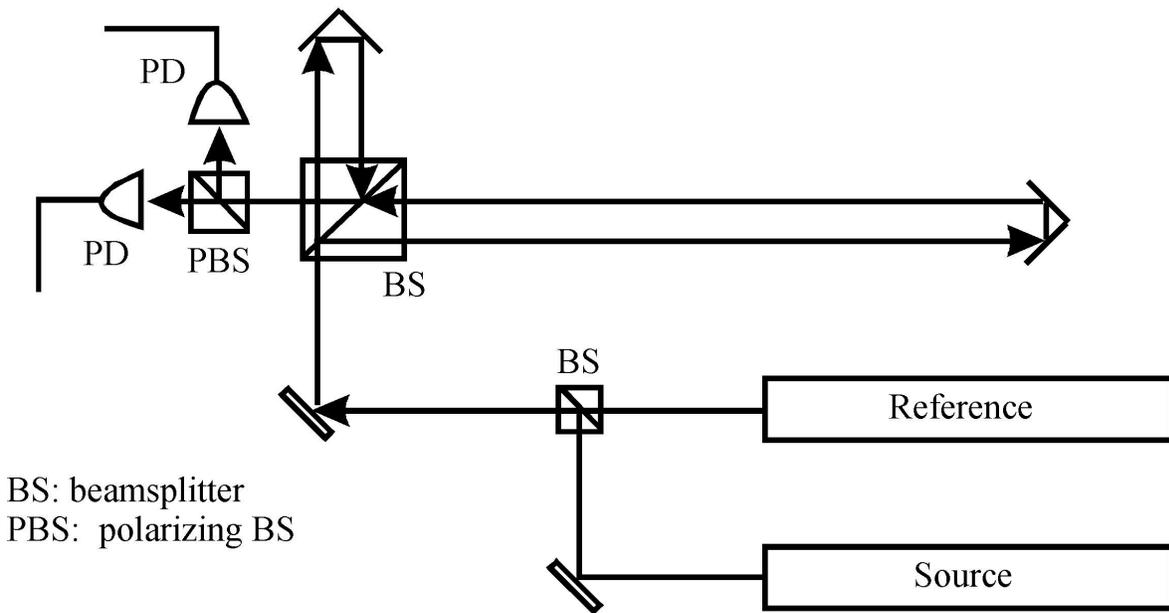


Figure 2. Wavemeter

(PBS), the beams from the two lasers can be superimposed on each other and aligned through the wavemeter. This allows the two beams to propagate the same optical path length through the interferometer. The beams are then separated at the exit of the interferometer and sent to two different photodetectors. If necessary, use color filters to further suppress the unwanted beam at the detectors. We then can obtain data from “two” interferometers. You will notice two practical problems with this arrangement:

1. The translation axis of the variable arm has to be lined up with the beam with great accuracy;

2. Due to diffraction, it is difficult to observe uniform extinction (and therefore good fringe contrast) over the cross section of the beam.

Both problems can be alleviated by changing the beam waist of the Gaussian beam emitted by the He-Ne laser. Indeed, the beam path in the long arm can be as much as 1 m longer than in the short arm. In order to produce interference fringes with the best possible contrast, the two beams must have the same intensity and therefore the same cross-section. This condition, for a delay variation of 2 m, implies some minimum dimension for the beam waist. What is this minimum size?

Expand the beam with an appropriate choice of lenses. You will notice that, while correcting problem (2), you have alleviated to some extent problem (1). It may also help to use a polarizer in front of the He-Ne laser. Observe the He-Ne interference fringes with and without a polarizer. The standard recording instrument used with a wavemeter is a frequency counter. That will be the first technique to use. By measuring the ratio of the fringe frequency from each laser as the mirror on the air rail is moved at a constant velocity, one should be able to calculate the frequency of the unknown laser. The alternative technique that will be used is to record all the data, store them, and make appropriate manipulations to determine the number of fringes passed from each laser. This is the more direct approach. The details on how to take data from the two photodiodes,  $D_s$  and  $D_r$ , and store it on the computer, are given in the Appendix. With this data, you can count the number of fringes, including the partial fringe, to calculate the frequency of the unknown laser.

### Summary

In this lab you should have learned how the Michelson interferometer can be used as a wavemeter to make precision measurements of a laser's frequency and wavelength. You should also try to identify some of the factors which limited the precision of your measurements.

### Additional questions

1. How is the precision of this technique affected by the distance which mirror 1 is translated? What does this tell you about the physical dimensions of a high-precision wavemeter?
2. Corner cube reflectors: The metallic corner cube reflectors have an accuracy of 2" of arc. Will that be sufficient to keep the laser beams aligned?
3. Fringe visibility and diffraction: Given as a condition that the beam diameter should not vary more than 10% over the entire range, in order to provide good fringe visibility, what should the initial waist of the beam be for each laser? (Hint: This requires some basic knowledge of Gaussian beam propagation.) You should estimate the size of the initial beam waist from each laser by measuring its far-field divergence angle.

### REFERENCES

1. Eugene Hecht, *Optics* (Addison, New York, 2002).