# Chapter 12 & 13: Quantum Physics

Wave vs. Particle description for e&m radiation as well as for "ordinary" matter via double-slit (in detail!)

Planck's Constant; $E = hf$ for photons; (of course also $c = f\lambda$, wave! )
de Broglie $\lambda = h/p = h/mv$; matter waves

Probabilities

Ch. 13: focus on Quantum Atom (13.6 & 13.7) before exam 3

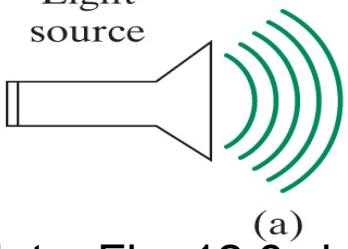
By the way: $E = hf = hc/\lambda = pc$ (←last step from classical E&M, Maxwell!), resulting in de Broglie's $\lambda = h/p$ ….. amazing!

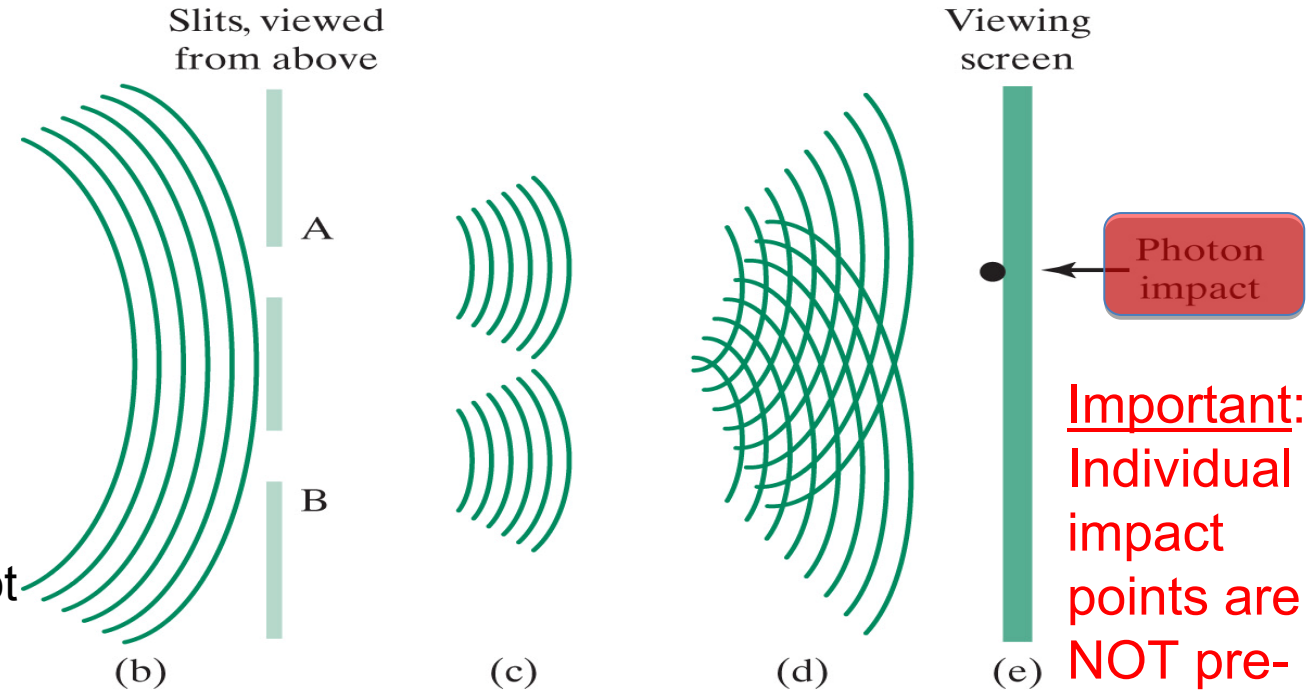
Which has the smaller de Broglie $\lambda$ (= h/p = h/mv), an electron or a proton?

(a) They have the same $\lambda$.
(b) electron
(c) proton
(d) Not enough info given.

<u>Quiz # 95</u>: Now electron and proton move with the <u>*same speed*</u>. Same question as above. Pick from the same answers.

# Light:

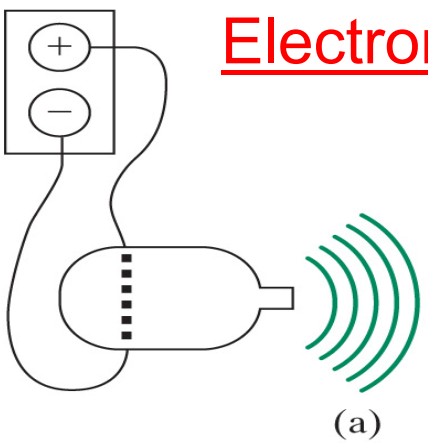


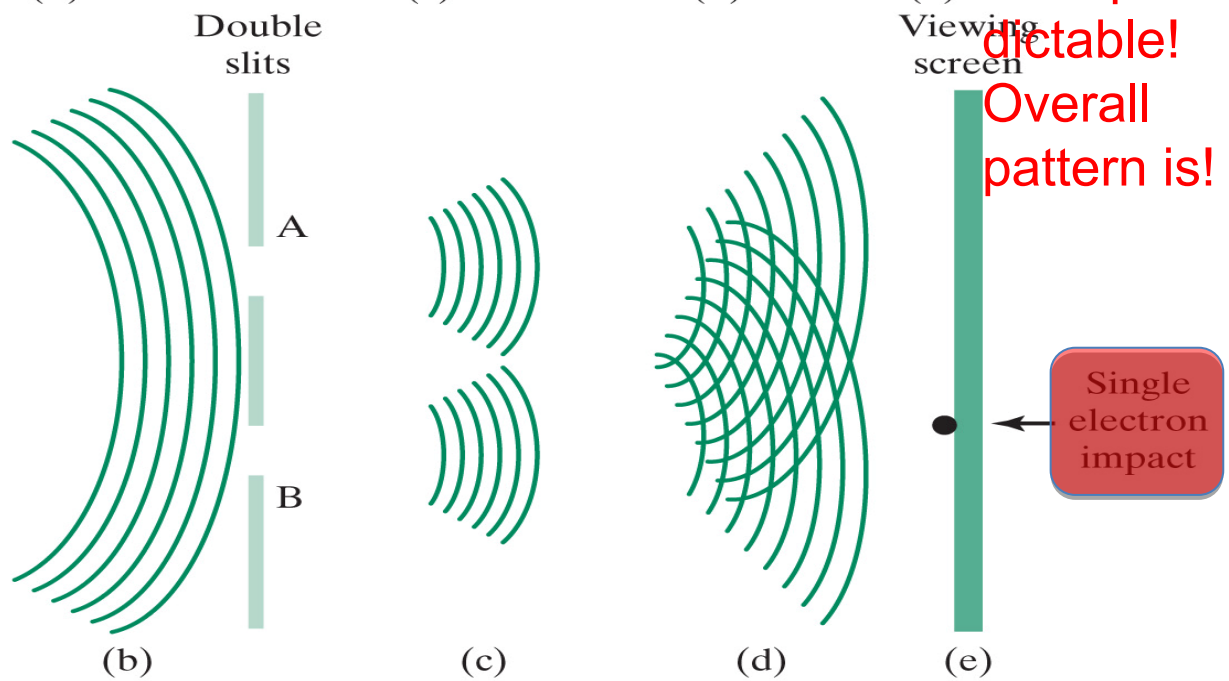




Note: Fig. 12.6 should say "**low intensity**", not "low energy" !

Important: Individual impact points are NOT pre-dictable! Overall pattern is!

# Electrons:




Again: **low intensity !**

Summary of important concepts & conclusions for *both* radiation and matter:

1) Fields are *real*, contain E, and are *quantized*.

2) At an interaction point (for instance screen) an E increment (say E = hf in the case of photons/radiation) from that field energy *suddenly "collapses"* to an interaction point (an atom) on the screen.

3) Through the slits comes a *spread-out wave* that interacts with the screen only at discrete points, as an "energy/momentum bundle", i.e. what we typically call a particle.

4) "Light is a wave that hits like a particle." And the same applies to "matter waves".

5) The medium for all these waves is the quantum field itself, i.e. e&m field or "matter field".

6) Electrons (or any other "particle") are just like photons – quanta (E/p – bundles) of a spread-out quantum field.

Cautionary word about E quantization for photons and (free!) electrons (or other particles)!

25. If electrons behaved only like particles and not like waves, would you observe an interference pattern in the double-slit experiment?
26. You don't notice the wave aspect of a pitched baseball. Is this because the baseball's wavelength is very long or because it is very short?
27. Arrange these in order from shortest to longest wavelength, assuming that they all have the same speed: helium atom, automobile, DNA molecule, electron, neutron, baseball.

<u>Quiz # 96</u>: Double-slit experiment with electrons – predictable are

(a) the electron's impact point

(b) the impact point and the overall interference pattern formed by many electrons

(c) only the overall interference pattern

(d) nothing is predictable, too much quantum weirdness!

Quiz # 97: In an electron double-slit experiment an electron strikes the screen directly behind slit A. Is it correct to say that the electron came through slit A?

(a) Yes (b) No (c) Depends upon λ of the electron

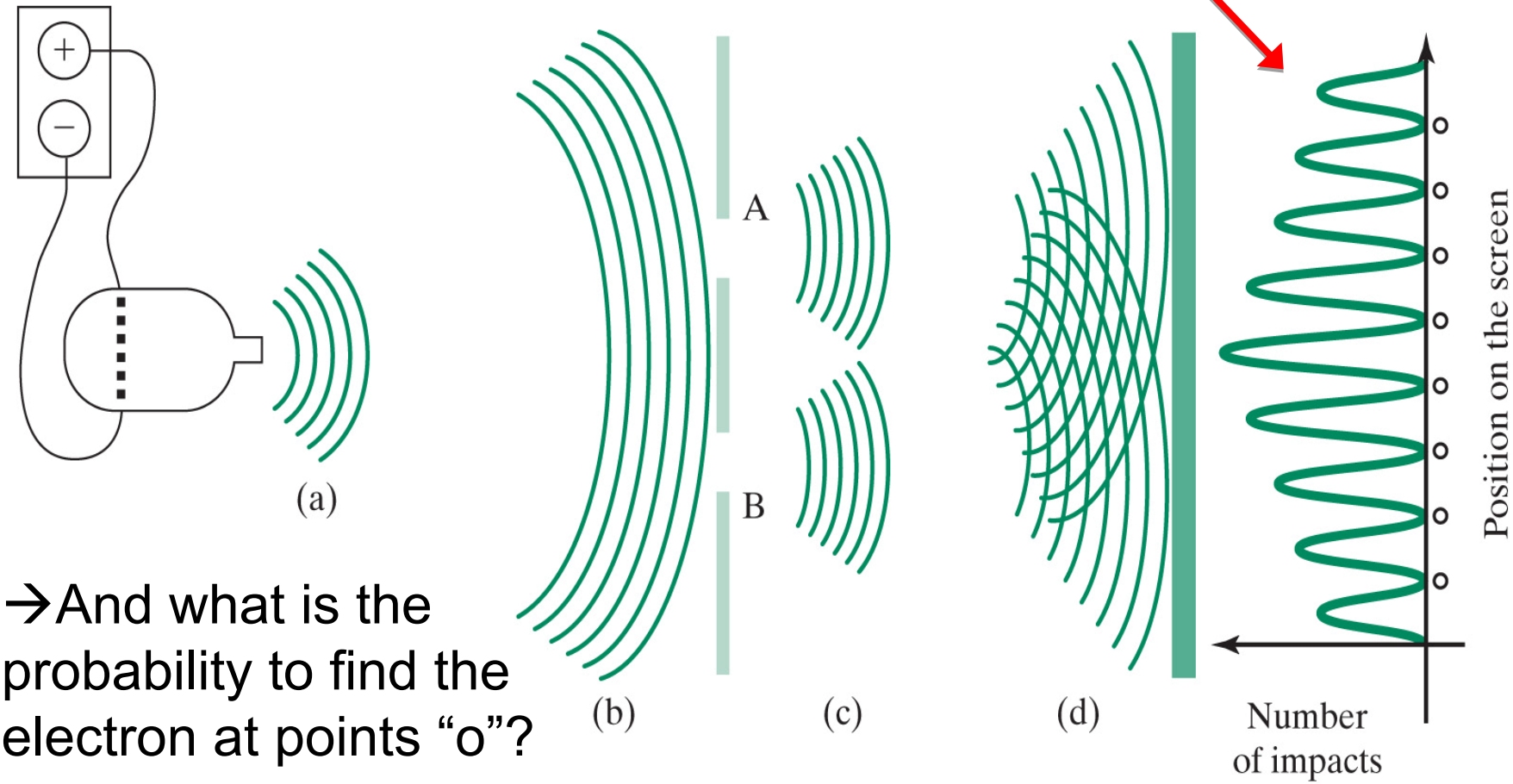
Characteristic Quantum Nonlocality& Quantum Uncertainty:

At the instant of the electron impact the entire, spread-out matter field/wave instantaneously deposits an energy quantum (a "particle") at the impact point. But the exact location of this impact point can NOT be predicted on an individual electron basis. Only the overall statistics are predictable – see next page.

→ Is matter discrete or continuous? Both – it's made of discrete quanta of a continuous field!

Impact distribution after lots of electrons,

which is a probability distribution !
("Born interpretation" of Quantum Mechanics – "wave function" Ψ)




→And what is the probability to find the electron at points "o"?

One more time because it's so much fun:

**→The essential quantum process we've discussed is the <u>nonlocal</u> collapse of the quantized e&m or matter field to an <u>uncertain</u> small interaction point.**

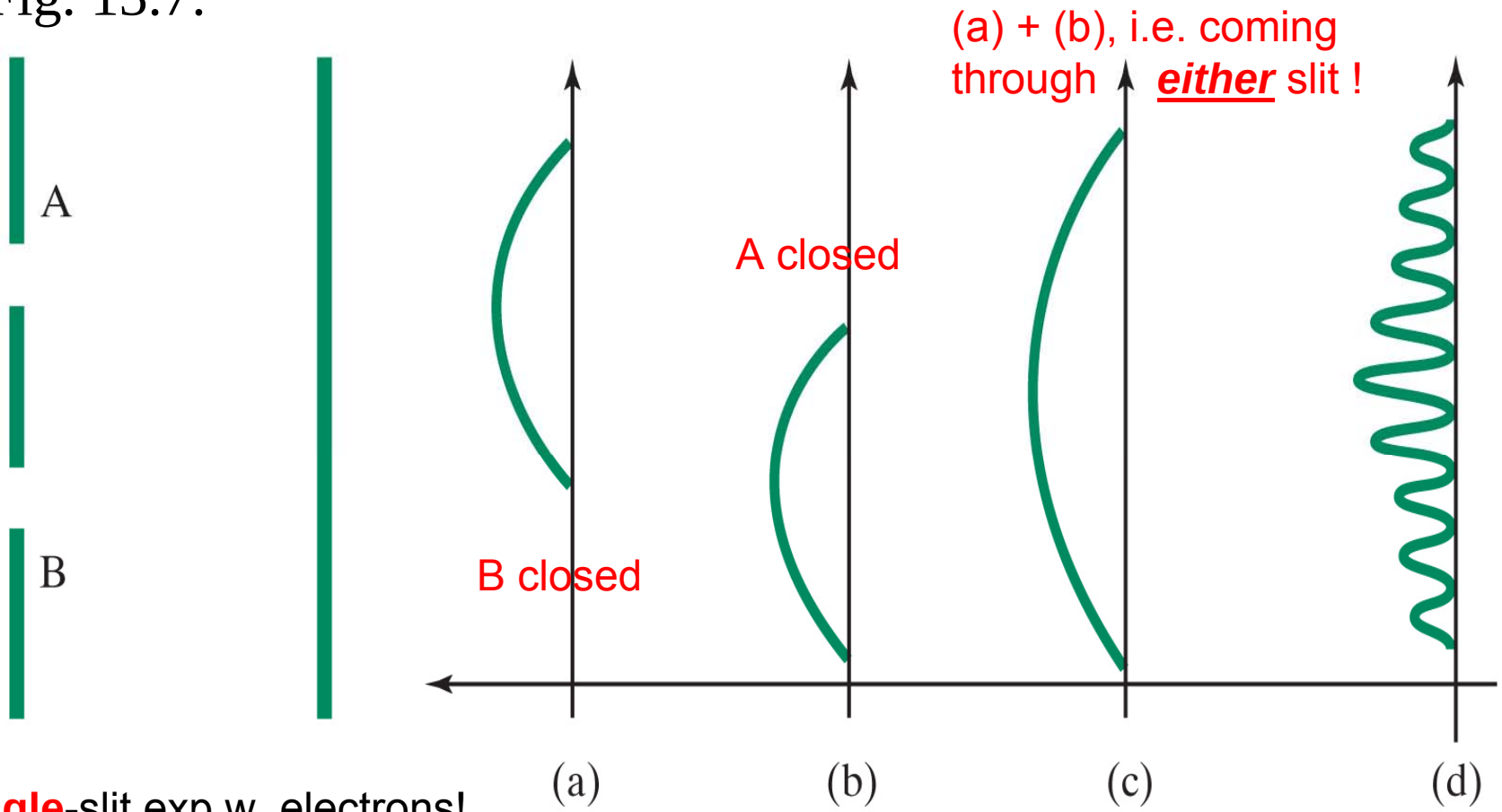
<u>Quiz # 98</u>: During a double-slit experiment using a *neutron* beam, the region between the slits and the screen contains

(a) a matter field.
(b) individual neutrons.
(c) an e&m field.
(d) a stream of photons.
(e) none of the above.

Probability is of course very much a classical concept.
BUT: outcome of quantum events are <u>*inherently uncertain*</u>, i.e.
"Nature herself doesn't know what the answer will be."
Makes many people *very*UNcomfortable (incl. Einstein!).

Brief comments on impact of "*measurement*"/detectors and the fascinating world of "*quantum entanglement:* (Ch. 13.2 & 13.3)

Fig. 13.7:

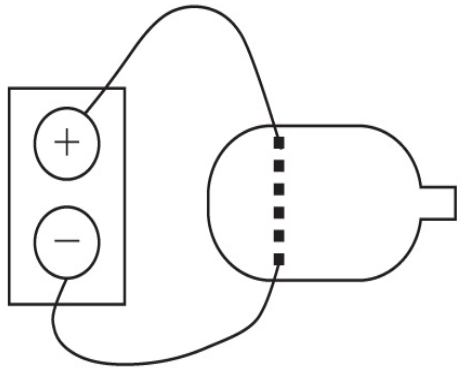




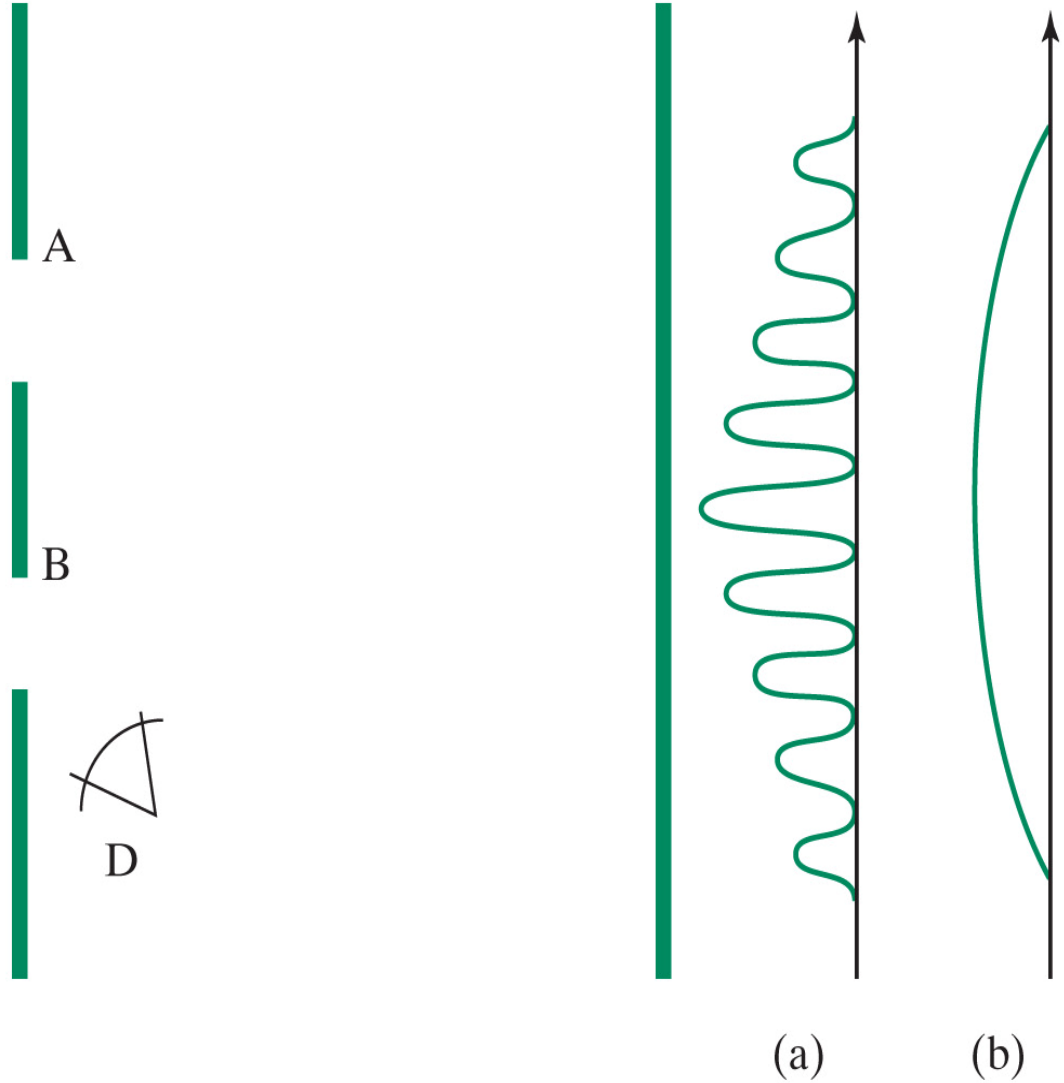

**Single**-slit exp w. electrons!
("bullets", see Feynman)

Actual **double**-slit result!

Fig. 13.8




Determining whether through A or B will change pattern from (a) to (b) !!






Example of “quantum entanglement” (“spooky” action at a distance – Einstein): two spin ½ electrons emitted from S = 0 state……amply experimentally verified.

# Atomic Spectra & the Quantum Atom (ch. 13.6 & 13.7)

Correct description of the observed atomic "spectra" and the observed **quantized atomic energy levels** – one of the earliest triumphs of Quantum Physics in the 1920s.

Essential topics:

Spectroscopy, particularly line spectra

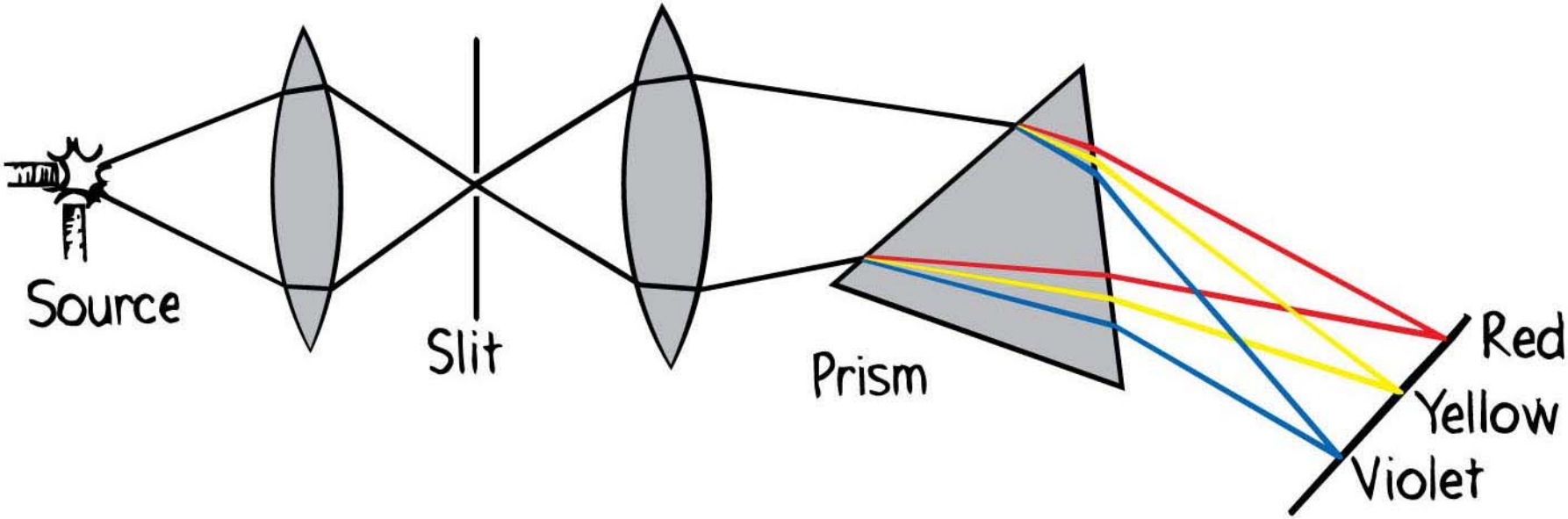
Energy quantization in hydrogen (atoms in general)

Quantum jumps – emission & absorption of photons

Probability distributions for the electron in H (hydrogen)

Various types of "*spectroscopy*", one of *the* most important tools in physics & chemistry & astronomy!

One example, prism spectrograph:






(→ raindrops leading to rainbows!)

Continuous vs. Line Spectra: glowing solids/liquids vs. gases at low pressure (inter-atomic interactions vs. isolated atoms):