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, de Broglie $\lambda$, matter waves
Probabilities
Ch. 13: focus on Quantum Atom (13.6 & 13.7) before exam 3
C.E. 5, 7, 9 – 12       Remember: $E_{\text{photon}} = hf$ (Planck)

**Quiz # 76:** Which has higher energy, a photon of infrared (IR) light or a photon of ultraviolet (UV) light?
(a) IR   (b) UV   (c) same energy   (d) depends on other things

**Quiz # 77:** Which of the two photons above is faster (in vacuum)?
(a) IR   (b) UV   (c) same speed   (d) depends on wavelength

**Famous direct evidence for photons:** Photo(-electric) effect (basis of many light sensors)
Remarkable: electrons (or other particles for that matter!) also show a double-slit interference pattern, thereby verifying de Broglie’s hypothesis of the (possible) wave nature of classical particles!

→ What waves here?  
A: a “probability (amplitude)” of finding the particle at the screen. Often referred to in quantum texts as the “wavefunction” ($\Psi$).

→ Sometimes (historically) called “wave-particle duality”

de Broglie’s relation:  
$\lambda = \frac{h}{p} = \frac{h}{mv}$  
(wavelength of matter waves = $h$/momentum)
Quiz # 78: Which has the smaller de Broglie $\lambda$, an electron or a proton?
(a) They have the same $\lambda$.
(b) electron
(c) proton
(d) Not enough info given.

Quiz # 79: Now electron and proton move with the same speed. Same question as above. Pick from the same answers.
Light:

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

Electrons:

Important: Individual impact points are NOT predictable! Overall pattern is!

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)!

Quiz # 80: 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 #81: 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 \( \lambda \) 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” \( \Psi \))

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

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One more time because it’s so much fun:

→ The essential quantum process we’ve discussed is the nonlocal collapse of the quantized e & m or matter field to an uncertain small interaction point.

Quiz # 82: 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 inherently uncertain, i.e. “Nature herself doesn’t know what the answer will be.”
Makes many people very UNcomfortable (incl. Einstein!).
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.

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):

(a) incandescent bulb

(b) hydrogen

(c) sodium

(d) mercury