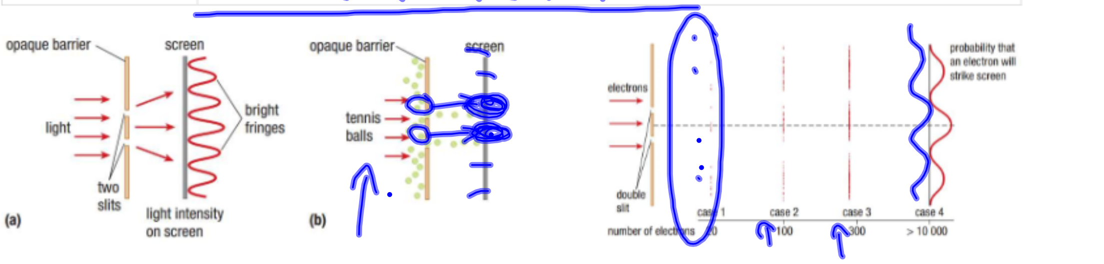
SPH4U 12.1 Introducing Quantum Theory

1. Intro to quantum

Quantum:	the smallest amount of energy that a particle can emit or absorb (plural = quanta).
Quantum theory:	energy is governed by these quanta; also, energy can behave as either particles or waves.
Double-slit experiment:	remember the double-slit exp. from Unit 4.
how waves behave	a wave travels through its medium, and arrives at both slits simultaneously. each slit acts like a new source, and the 2 sources interfere, creating bands of interference on the screen.
how particles behave	imagine tennis balls. each one goes through one slit, the other, or neither (blocked by the barrier). they go through the slit and hit the screen - no interference pattern.



what electrons do	electrons are fired 1 at a time as particles, but create interference patterns. each electron goes through both slits and interferes with itself!
Wave-particle duality:	all quantum objects can have interference, and all transfer energy in discrete amounts.

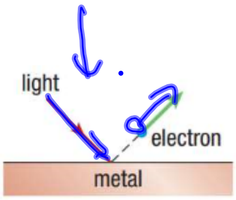
Homework: pg. 619 #3, 8

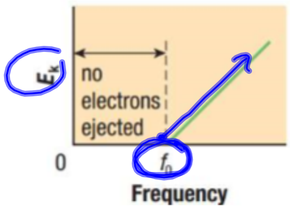
SPH4U 12.2 Photons and the Quantum Theory of Light

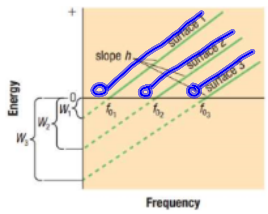
1. Work function and photoelectric effect

Light is a wave:	by the late 1800s, everyone agreed light was a wave (Young's double-slit, Maxwell's equations).
but not actually	turns out they were wrong. kind of.

Work function:	minimum energy needed to remove an electron from a metal surface.
equation	$W = e\Delta V$. Units: eV (electron-volts).
Photon energy:	$E_{photon} = hf$.
Planck's constant	$h = 6.63 \times 10^{-34}$ J·s. a very important constant.







Aluminum is being used in a photoelectric effect experiment. The work function of aluminum is 6.73×10^{-19} J.

a. Calculate the minimum photon energy and frequency needed to emit electrons.

$E_{photon} > 6.73 \times 10^{-19}$ J.

$E_{photon} = hf$

$$f = \frac{E_{photon}}{h} = \frac{6.73 \times 10^{-19}}{6.63 \times 10^{-34}}$$

$$= 1.02 \times 10^{15} \text{ Hz.}$$

b. Incident blue light of wavelength 450 nm is used in the experiment. Determine whether any electrons are emitted, and if they are, their maximum kinetic energy.

$E_{photon} > W?$

$E_{photon} = hf$

$v = f\lambda$

$f = \frac{v}{\lambda} = \frac{3.0\times10^{8}}{450\times10^{-9}} = \underline{6.667\times10^{14}\ Hz}$

$E_{photon} = hf$

$= (6.63\times10^{-34})(6.67\times10^{14})$

$= 4.4\times10^{-19}\ J$

$\therefore \underline{E_{photon} < W}$.

2. Photon momentum

Photon momentum:	$p_{photon} = \frac{hf}{c} = h\lambda$.

A certain AM radio station has a frequency near 1.0 MHz, and a certain FM station has a frequency near 110 MHz. Radio waves are electromagnetic waves, so the radio waves produce photons.

a. Compare the momentum of the photons from the AM station with the momentum of the photons from the FM station.

AM: $p_{photon} = \frac{hf}{c} = \frac{(6.63\times10^{-34})(1.0\times10^{6})}{3.0\times10^{8}}$

$= \underline{2.2\times10^{-36}\ kg\cdot m/s}$.

FM: $p_{photon} = \frac{hf}{c} = \frac{(6.63\times10^{-34})(110\times10^{6})}{3.0\times10^{8}}$

$= \underline{2.4\times10^{-34}\ kg\cdot m/s}$.

b. Compare the energy of the photons from the AM and FM stations.

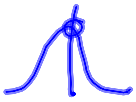
AM: $E_{photon} = hf$

$= (6.63\times10^{-34})(1.0\times10^{6}) = \underline{6.6\times10^{-28}\ J}$.

FM: $E_{photon} = hf$

$= (6.63\times10^{-34})(110\times10^{6}) = \underline{7.3\times10^{-26}\ J}$.

3. Blackbody radiation



Blackbody:	an object that absorbs all radiation reaching it, and emits its own radiation.
Wien's law	gives the wavelength that is emitted most intensely from a blackbody.
equation	$\lambda_{max} = \frac{2.90 \times 10^{-3}\ m \cdot K}{T}$, T is Temperature in K.

Use the table below to determine the colour of a blackbody that radiates at 4143 K and a blackbody that radiates at 6444 K.

Colour	Wavelength range (m)
red	6.25×10^{-7} to 7.40×10^{-7}
orange	5.90×10^{-7} to 6.25×10^{-7}
yellow	5.65×10^{-7} to 5.90×10^{-7}
green	5.20×10^{-7} to 5.65×10^{-7}
cyan	5.00×10^{-7} to 5.20×10^{-7}
blue	4.35×10^{-7} to 5.00×10^{-7}
violet	3.80×10^{-7} to 4.35×10^{-7}

① $\lambda_{max} = \frac{2.90 \times 10^{-3}}{4143}$

$= 7.00 \times 10^{-7}\ m$

∴ it emits red.

② $\lambda_{max} = \frac{2.90 \times 10^{-3}}{6444\ K}$

$= 4.50 \times 10^{-7}\ m$.

∴ it emits blue.

Homework: pg. 631 #1-4

SPH4U 12.3 Wave Properties of Classical Particles

1. de Broglie wavelength

de Broglie wavelength:	any particle with momentum p can be seen as a wave with wavelength λ.
equation	$\lambda = \frac{h}{p}$
Electron double-slit experiment:	electrons interfere the same as photons!

In their studies of interference with electrons, Davisson and Germer used electrons with a kinetic energy of approximately 50 eV, which equals 8.0 x 10^{-18} J. The mass of an electron is 9.11 x 10^{-31} kg.

a. Calculate the de Broglie wavelength of these electrons in metres and nanometres.

$E_K = \frac{1}{2}mv^2$

$v = \sqrt{\frac{2E_k}{m}} = \sqrt{\frac{2(8.0\times10^{-18})}{9.11\times10^{-31}}}$

$= 4.19\times10^{6}\ m/s$

$p = mv$

$= (9.11\times10^{-31})(4.19\times10^{6})$

$= 3.82\times10^{-24}\ kg\,m/s.$

$\lambda = \frac{h}{p} = \frac{6.63\times10^{-34}}{3.82\times10^{-24}}$

$= 1.74\times10^{-10}\ m = 0.174\ nm$

b. The spacing between atoms in a typical crystal is about 0.3 nm. How does this spacing compare with the wavelength of the electrons used by Davisson and Germer?

λ is less than 0.3 nm, but it is a similar size.

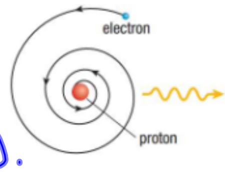
Collapse interpretation:	electron starts as a particle, spreads out as a wave, then "collapses" as a particle when it has to "decide".
Many worlds interpretation:	Universe constantly splits into many versions. 2 worlds are created, for the electron going left or right.
Copenhagen interpretation:	there is no correct answer to what they are "doing" - only what we can measure is meaningful.

Homework: pg. 639 #1-3

SPH4U 12.6 The Standard Model of Elementary Particles

1. The standard model

Planetary model:	when an orbiting electron emits energy, (light), it should spiral into the nucleus.
solution	Bohr model: electrons can only have certain values of energy (energy levels)(quanta).
Antimatter:	particle with the same mass and opposite charge as a normal particle (electron+positron, neutron:anti-neutron).



The standard model:	all matter is made up of quarks and leptons.
quarks	6 kinds (flavours): up (u), down (d), charm (c), strange (s), top (t), bottom (b).
charge	all quarks have charge of either $+\frac{2}{3}e$ or $-\frac{1}{3}e$.
anti-quarks	each quark has an anti-quark, i.e. $\bar{u}$, $\bar{d}$
Hadrons:	particles made up of 2 or more quarks.
baryons	3 quarks: proton (uud), neutron (udd).
mesons	1 quark and 1 anti-quark.
Leptons:	other elementary particles (not quarks), i.e. electron.
Fermions:	quarks and leptons - the particles of matter.
Bosons:	field particles - transmit forces between fermions.

Theory of everything:	a theory to combine the three fundamental forces (weak, strong, electromagnetic) with gravity into a single theory.

Homework: pg. 653 None!