AP Physics – Quantum Wrap Up

Not too many equations in this unit. Just a few. Here they be:

$$E = hf = pc$$

This is the equation for the energy of a photon. The hf part has to do with Planck's constant and frequency. The other part, the pc bit, shows that the energy is a function of the photon's momentum (p) and the speed of light (c).

$$K_{\max} = hf - \phi$$

This is the equation for the maximum kinetic energy of an electron that has been expelled from a metal by a photon. hf is the energy of the photon and the ϕ part is the work function for the metal. Note that the electron can have less energy than this, it just represents a maximum.

$$\lambda = \frac{h}{p}$$

This is an equation for the wavelength of a photon as a function of its momentum and Planck's constannt.

$$\Delta E = (\Delta m) c^2$$

This is a ridiculously complicated way to write Einstein's famous $E = mc^2$ equation. What this one is saying is that energy and mass are equivalent to each other. This means that when a system undergoes change in energy, there will be a change in mass as well – the mass being converted into energy, see?

$$v = f\lambda$$

This equation is not part of the modern physics equation set, but is needed to solve the problems. Using it, one can relate frequency and wavelength. For many of the problems you will be tasked to solve, you will be given wavelength and not frequency of the photons. Using this equation, you can properly work things out.

Modern Physics

A. Atomic Physics and Quantum Effects

1. You should know the properties of photons and understand the photoelectric effect so you can:

a. Relate the energy of a photon in joules or electron-volts to its wavelength or frequency.

Just use the $E = hf = pc$ equation. Actually you want the $E = hf$ part of it. To get the wavelength thing in there, use the $v = f\lambda$ so $c = f\lambda$ equation. Solve for f and plug that into the first equation. You get $E = \frac{hc}{\lambda}$.

b. Relate the linear momentum of a photon to its energy or wavelength, and apply linear momentum conservation to simple processes involving the emission, absorption, or reflection of photons.

Use the $E = hf = pc$ equation. Mainly though, you use the $E = pc$ part of it.

c. Calculate the number of photons per second emitted by a monochromatic source of specific wavelength and power.

Power is work divided by time, which means that it is also energy divided by time. Use the $E = hf$ equation to calculate the energy for one photon. You know the total amount of energy in **one second (it's just the power) so you can divide it by the energy of a photon to g***et the number of photons per second.*

d. Describe a typical photoelectric effect experiment, and explain what experimental observations provide evidence for the photon nature of light.

This would require you to describe a typical photoelectric tube. You would want to talk about the emitter and the collector. Also talk about the stopping potential that is applied to the collector and how it affects the photoelectrons. The key thing for the photon nature of light (by this they mean the particle nature of light) is that the photons are having collisions with electrons and knocking them out of the metal, giving them (the electrons) kinetic energy. The photoelectric equation allows you to calculate the maximum kinetic energy one of these photoelectrons can have.

e. Describe qualitatively how the number of photoelectrons and their maximum kinetic energy depend on the wavelength and intensity of the light striking the surface, and account for this dependence in terms of a photon model of light.

The wavelength of the light determines the amount of energy each photon has. If the energy is too small (the wavelength is not short enough or the frequency is too small) then no **photoelectrons are emitted. The photons don't have enough energy to break the electrons loose.** *The work function can be thought of as the energy that binds the electrons to the metal. If the photon has more energy than the work function, electrons will be knocked out of the metal. If* **the photon's energy is less than the work function no photoele***ctrons are produced.*

The energy of the photon is a function of its wavelength. The shorter the wavelength the greater the energy. It is also a function of its frequency. The bigger the frequency the bigger the energy of the photon.

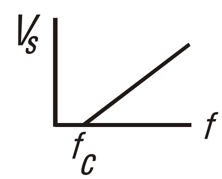
The intensity of the light is a measure of the number of photons per second that are incident on the metal surface. If the wavelength is too large to produce photoelectrons, the intensity of the light will have no effect. No photoelectrons will be produced.

If the wavelength is suitable to produce photoelectrons, the intensity will determine the number that are released. The intensity will have no effect on the energy of the photoelectrons however, just their number.

f. When given the maximum kinetic energy of photoelectrons ejected by photons of one energy or wavelength, determine the maximum kinetic energy of photoelectrons for a different photon energy or wavelength.

Use the $K_{\max} = hf - \phi$ *equation. You are given the maximum kinetic energy and the energy of the photons (or wavelength) so you can calculate the work function,* ϕ*. Then using the work function and the new photon energy you can work out the maximum kinetic energy of the photoelectrons for the new wavelength.*

g. Sketch or identify a graph of stopping potential versus frequency for a photoelectric-effect experiment, determine from such a graph the threshold frequency and work function, and calculate an approximate value of *h/e*.



Here is a typical graph. The f_C *term is the threshold frequency. It is simply where the curve hits the old x axis. Photons that have a higher frequency than the cutoff frequency will produce photoelectrons that have enough energy to reach the collector, overcoming the electric field establish on the thing. Photons at the threshold frequency will have a maximum kinetic energy that is equal to the potential energy of the field.*

To find the work function, okay. Let's see. At the threshold frequency the maximum kinetic *energy of the photoelectrons is equal to the potential energy in the field so:*

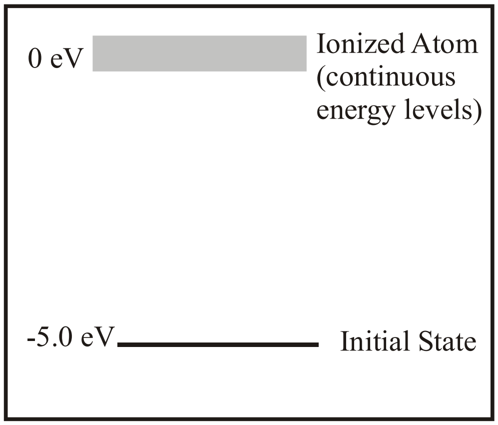
$K_{\max} = hf - \phi$ *and* $U = qV$ *so* $qV = hf - \phi$ *at the threshold frequency, the stopping potential is zero, so* $0 = hf - \phi$ *and* $\phi = hf_C$*. So the work function is simply the threshold* ***frequency times Plank's constant.***

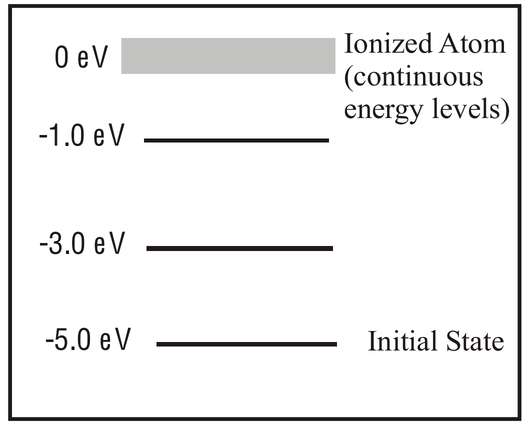
The energy of a photon is $E = hf$ *and the potential energy of the field is* $U = qV$*. Set them equal and you get* $hf = qV$ *q is* ***the charge of an electron, so we can plug in "e" for the electron's charge and write the equation as:*** $hf = eV$ *solving for* $\frac{h}{e}$ *like they want us to do we get:* $\frac{h}{e} = \frac{V}{f}$ *Thus, h/e is simply the slope of the graph.*

2. You should understand the concept of energy levels for atoms so you can:

   a. Calculate the energy or wavelength of the photon emitted or absorbed in a transition between specified levels, or the energy or wavelength required to ionize an atom.

Okay. This is the one where you have the energy diagrams. They look like this:





The one on the left you would use to determine the energy needed to ionize an atom. The one the right gives you the specified energy levels that are available for the electrons to make their quantum leap things to. (The Physics Kahuna recognizes that that was a really wretched sentence – ***but, he doesn't care.) Electrons absorb photons that have energy that is equal to the*** *energy differences between the energy levels. The wavelength or the frequency of the photons can be calculated because you know the energy that is needed to make the quantum leaps. We did several of these problems and the whole thing was wonderfully explained in the handout. What a lucky AP student you are to have such a splendiferous resource!*

b. Explain qualitatively the origin of emission or absorption spectra of gases.

The "qualitatively" thing is nice. It means that you don't have to calculate anything, just explain *it On second thought,* ***maybe that's not so good. It is always easier to calculate something than*** *to explain it. Gas atoms that are excited will give off an emission spectrum. These are photons of specific wavelengths that represent the energy levels within the atom. The excited electrons jump up to higher energy levels, are not stable, and fall back down to lower energy levels. The energy difference between the energy levels is given off as a photon by the electron. SO the only colors given off correspond to the energy level differences in the atom. The spectrum given off appears as different colored lines. You will recall having viewed just such a thing.*

The absorption spectra has to do with white light (all colors) shining through a gas sample. The photons of light that have wavelengths that correspond to the energy levels in the atoms of the gas are absorbed. The spectrum is continuous – goes from red to violet, but the absorbed wavelengths show up as dark lines where there is no light.

c. Given the wavelengths or energies of photons emitted or absorbed in a two-step transition between levels, calculate the wavelength or energy for a single-step transition between two levels.

This is pretty simple - just calculate the energy of the photon from its wavelength and then convert it into eV. You can then translate that into the energy levels in the atom. We did a ***bunch of problems like that. Check 'em out.***

3. You should understand the concept of DeBroglie wavelength so you can:

a. Calculate the wavelength of a particle as a function of its momentum.

The DeBroglie wavelength is the flip side of the coin for matter. The idea is that moving particles such as electrons have wave characteristics – frequency, wavelength, &tc. Also that the particles can undergo wave interactions such as constructive and destructive interference, producing interference patterns.

Just use the $\lambda = \frac{h}{p}$ *equation. It gives you the wavelength as a function of momentum. The equation is for a wave, but it also works for particles as well. Of course the momentum of a particle is simply* $p = mv$.

b. Describe the Davisson-Germer experiment, and explain how it provides evidence for the wave nature of electrons.

Okay, this is a classic experiment that took place in 1927. Two guys, Davisson and Germer, measured the wavelength of electrons that were scattered off a nickel target in a vacuum. The crystal structure of the nickel acted like a diffraction grating. The scattered electrons exhibited interference patterns – you know the whole minima and maxima deal at specific angles. This ***was confirmation of DeBroglie's theory of particle wave behavior.***

4. You should understand the nature and production of x-rays so you can calculate the shortest wavelength of x-rays that may be produced by electrons accelerated through a specified voltage.

x-rays are produced when high velocity electrons are incident on a dense metal such as tungsten. If we assume that the energy of the electron is converted into the energy of the x-ray photon produced, then we get:

$$U = qV \quad E = hf \qquad v = \lambda f = c \qquad so \qquad qV = \frac{hc}{\lambda} \qquad so \qquad \lambda = \frac{hc}{qV}$$

Where q is the charge of the electron and V is the potential difference that the electron was accelerated through.

5. You should understand Compton scattering so you can:

a. Describe Compton's experiment, and state what results were observed and by what sort of analysis these results may be explained.

The Compton thing is that a beam of x-rays are flashed onto a graphite crystal. The x-ray beam is made up of a stream of photons. The photons, acting like particles, collide with electrons in the carbon atoms in the graphite. The photons give some of their energy to the electrons. Now, having less energy than before, the photons end up with a longer wavelength. For a photon less energy means longer wavelength. This was good evidence for the particle nature of electromagnetic waves.

b. Account qualitatively for the increase of photon wavelength that is observed, and explain the significance of the Compton wavelength.

. The important thing is that increase in photon wavelength is due to the loss of photon energy in the collision between the photons and electrons.

B. Nuclear Physics

1. You should understand the significance of the mass number and charge of nuclei so you can:

a. Interpret symbols for nuclei that indicate these quantities.

It's just like the thing over here to the right. Mass number, *atomic number, and the elements chemical symbol.*

mass number

$$^{14}_{6}C$$

symbol

atomic number

b. Use conservation of mass number and charge to complete nuclear reactions.

Okay, this is simple. The basic idea is that the atomic number and mass numbers are conserved in a nuclear reaction. This means that the total atomic number on one side of the equation must equal the total atomic number on the other side. Same deal for the mass number.

c. Determine the mass number and charge of a nucleus after it has undergone specified decay processes.

Three kinds of decay to worry about – alpha decay, beta decay, and gamma decay. In alpha decay, the nucleus loses an alpha particle, which is a He-4 nucleus. In Beta decay the nucleus loses an electron. Gamma decay is usually a byproduct of either alpha or beta decay.

In alpha decay, the mass number of the parent nuclei goes down by four and atomic number goes down by two. In beta decay the mass number stays the same but the atomic number increases by one. The gamma photon has no effect on either mass number or atomic number.

c. Describe the process of α, β, γ decay and write a reaction to describe each.

Here are a couple of example equations.

$$^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He \quad \textit{Alpha decay}$$

$$^{234}_{90}Th \rightarrow {}^{234}_{91}Pa + {}^{0}_{-1}e \quad \textit{Beta decay}$$

e. Explain why the existence of the neutrino had to be postulated in order to reconcile experimental data from β decay with fundamental conservation laws.

A particle accelerator was used to bombard an atomic nucleus with a high-energy particle. Energy and momentum would have to be conserved, but when the properties of the particles were examined after the collision, the energy and momentum did not add up. There had to be another particle that had the missing energy and momentum. A new particle had to exist and

was postulated. Later it was given the name "neutrino" by Enrico Fermi. It wasn't until the mid 1950's that the neutrino was actually detected.

Here's an example of a reaction that produces a neutrino (this would be beta decay, right?):

$${}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e + \nu$$ *The symbol for the neutrino is* ν.

2. You should know the nature of the nuclear force so you can compare its strength and range with those of the electromagnetic force.

The nuclear force binds the nucleons together within the nucleus. It is many orders of magnitude stronger than the electromagnetic force. Its effective range, however, is very small – essentially the particles have to be really close together, like almost touching, before the strong nuclear force is greater than the electromagnetic force.

So its strength is much greater than the electromagnetic force but it is a much shorter range deal.

3. You should understand nuclear fission so you can:

   a. Describe a typical neutron-induced fission and explain why a chain reaction is possible.

By using the phrase "describe", the College Board folks are telling you that you don't need to *write out an actual fission equation, but simply to state what happens in one. This is pretty* ***simple. Okay here's what happens: a heavy nucleus, like*** *your basic U-235, absorbs a neutron.* ***This makes it unstable, and it splits apart. This is the "fission" part of the deal. It becomes two*** *new nuclei. Stuff like barium and krypton.*

Now why is a chain reaction possible?

   b. Relate the energy released in fission to the decrease in rest mass.

Just use the $\Delta E = (\Delta m)c^2$ *equation. The energy released (the* ΔE *deal) is equal to the change in the rest mass (the* Δm *deal) times the speed of light squared. You just use the equation.*

From 2001:

- Consider the following nuclear fusion reaction that uses deuterium as fuel.

$$3\left({}^{2}_{1}\mathrm{H}\right) \rightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{1}\mathrm{H} + {}^{1}_{0}\mathrm{n}$$

(a) Determine the mass defect of a single reaction, given the following information.

$${}^{2}_{1}\mathrm{H} = 2.0141\ \mathrm{u} \qquad {}^{4}_{2}\mathrm{He} = 4.0026\ \mathrm{u} \qquad {}^{1}_{1}\mathrm{H} = 1.0078\ \mathrm{u} \qquad {}^{1}_{0}\mathrm{n} = 1.0087\ \mathrm{u}$$

Okay, this is simple, just add up all the masses and then compare it to the mass of a helium nuclei plus a proton and a neutron. We will subtract the individual parts from the mass of the three deuterium nuclei.

$$3(2.0141\ u) - 4.0026\ u - 1.0078\ u - 1.0087\ u \quad = \quad \boxed{0.0232\ u}$$

(b) Determine the energy in joules released during a single fusion reaction.

$$0.0232\ \cancel{u}\left(\frac{1.66\ x10^{-27}\ kg}{1\ \cancel{u}}\right) \quad = 0.0385\ x10^{-27}\ kg \quad = 3.85\ x10^{-29}\ kg$$

$$\Delta E = (\Delta m)c^2 \quad = 3.85\ x10^{-29}\ kg\left(3.0\ x10^{8}\ \frac{m}{s}\right)^2 \quad = 34.65\ x10^{-13}\ J \quad = \quad \boxed{3.46\ x10^{-12}\ J}$$

(c) The United States requires about 10^{20} J per year to meet its energy needs. How many deuterium atoms would be necessary to provide this magnitude of energy?

$$10^{20}\ \cancel{J}\left(\frac{1\ \ nuclei}{3.46\ x10^{-12}\ \cancel{J}}\right) \quad = 0.289\ x10^{32}\ \ nuclei \quad = \quad \boxed{2.89\ x10^{31}\ \ nuclei}$$

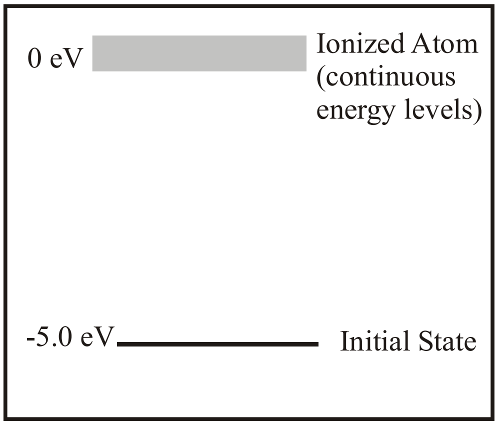
(d) Assume that 0.015% of the hydrogen atoms in seawater (H_2O) are deuterium. The atomic mass number of oxygen is 16. About how many kilograms of seawater would be needed per year to provide the hydrogen fuel for fusion reactors to meet the energy needs of the United States?

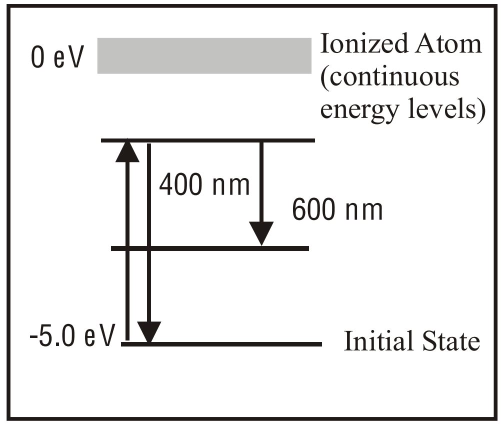
$$2.89\ x10^{31}\ \cancel{nuclei}\left(\frac{1\ \cancel{molecule}}{2\ \cancel{nuclie}}\right)\left(\frac{1\ \cancel{mol}}{6.02\ x10^{23}\ \cancel{molecule}}\right)\left(\frac{18\ \cancel{g}}{1\ \cancel{mol}}\right)\left(\frac{1\ kg}{10^{3}\ \cancel{g}}\right) \quad = 4.3\ x10^{5}\ kg$$

$$4.3\ x10^{5}\ kg\left(\frac{1}{0.00015}\right) \quad = \quad \boxed{3\ x10^{9}\ kg}$$

From 1997:

- A monatomic gas is illuminated with visible light of wavelength 400 *nm*. The gas is observed to absorb some of the light and subsequently to emit visible light at both 400 *nm* and 600 *nm*.





a. In the box, (above) complete an energy level diagram that would be consistent with these observations. Indicate and label the observed absorption and emissions.

b. If the initial state of the atoms has energy - 5.0 *eV*, what is the energy of the state to which the atoms were excited by the 400 *nm* light?

$$E = hf \qquad f = \frac{c}{\lambda} \qquad E = \frac{hc}{\lambda}$$

$$E = \frac{hc}{\lambda} = \frac{\left(1.24\ x10^3\ eV \cdot \cancel{nm}\right)}{400\ \cancel{nm}} = 3.1\ eV$$

$$E_e = -5.0\ eV + 3.1\ eV = \boxed{-1.9\ eV}$$

c. At which other wavelength(s) outside the visible range do these atoms emit radiation after you are excited by the 400 *nm* light?

$$E = \frac{hc}{\lambda} = \frac{\left(1.24\ x10^3\ eV \cdot \cancel{nm}\right)}{600\ \cancel{nm}} = 2.1\ eV$$

$$E_e = 3.1\ eV - 2.1\ eV = 1.0\ eV$$

$$E = \frac{hc}{\lambda} \qquad \lambda = \frac{hc}{E} = \frac{1.24\ x10^3\ \cancel{eV} \cdot nm}{1.0\ \cancel{eV}} = \boxed{1240\ nm}$$

From 1996:

- An unstable nucleus that is initially at rest decays into a nucleus of fermium-252 containing 100 protons and 152 neutrons and an alpha particle that has a kinetic energy of 8.42 MeV. The atomic masses of helium-4 and fermium-252 are 4.00260 u and 252.08249 u, respectively.

  a. What is the atomic number of the original unstable nucleus?

  $Z = 102$

  b. What is the velocity of the alpha particle? (Neglect relativistic effects for this calculation.)

$$K = \left(8.42\ x10^{6}\ \cancel{e}V\right)\left(\frac{1.6\ x10^{-19}\ J}{1\ \cancel{e}V}\right) = 1.35\ x10^{-12}\ J$$

$$m = 4.0\ \cancel{u}\left(\frac{1.67\ x10^{-27}\ kg}{1\ \cancel{u}}\right) = 6.68\ x10^{-27}\ kg$$

$$K = \frac{1}{2}mv^2 \quad v = \sqrt{\frac{2K}{m}} = \sqrt{\frac{2\left(1.35\ x10^{-12}\ \frac{\cancel{kg}\cdot m^2}{s^2}\right)}{6.68\ x10^{-27}\ \cancel{kg}}}$$

$$v = \sqrt{0.4042\ x10^{15}\ \frac{m^2}{s^2}} = \sqrt{4.042\ x10^{14}\ \frac{m^2}{s^2}} = \boxed{2.01\ x10^{7}\ \frac{m}{s}}$$

  c. Where does the kinetic energy of the alpha particle come from? Explain briefly.Where does the kinetic energy of the alpha particle come from? Explain briefly.

Mass Equivalence: The original nucleus decays into the product particles and energy. The energy shows up primarily as the kinetic energy of the daughter nucleus and the particles that are emitted. Energy Conservation is also involved – the potential or binding energy of the nucleus was converted into kinetic energy of the products of the reaction.

  d. Suppose that the fermium-252 nucleus could undergo a decay in which a β^- particle was produced. How would this affect the atomic number of the nucleus? Explain briefly.

Atomic number increases by one. A neutron converts into a proton and an electron.

$$^{252}_{100}Fm \rightarrow \ ^{252}_{101}X + \ ^{0}_{-1}e$$

*Note you would not have access to a periodic table, so you probably wou***ldn't know what element had an** *atomic number of 101.*

From 1995:

- A free electron with negligible kinetic energy is captured by a stationary proton to form an excited state of the hydrogen atom. During this process a photon of energy E_a is emitted, followed shortly by another photon of energy 10.2 electron volts. No further photons are emitted. The ionization energy of hydrogen is 13.6 electron volts.

a. Determine the wavelength of the 10.2 eV photon.

$$E = hf \quad c = f\lambda \quad f = \frac{c}{\lambda} \qquad E = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{E} = \frac{\left(4.14\ x10^{-15}\ \cancel{eV}\cdot\cancel{s}\right)\left(3\ x10^{8}\ \frac{m}{\cancel{s}}\right)}{10.2\cancel{eV}} = \boxed{1.22\ x10^{-7}\ m}$$

b. Determine the following for the first photon emitted.

i. The energy E_c of the photon

$$E_c = 13.6\ eV - 10.2\ eV = \boxed{3.4\ eV}$$

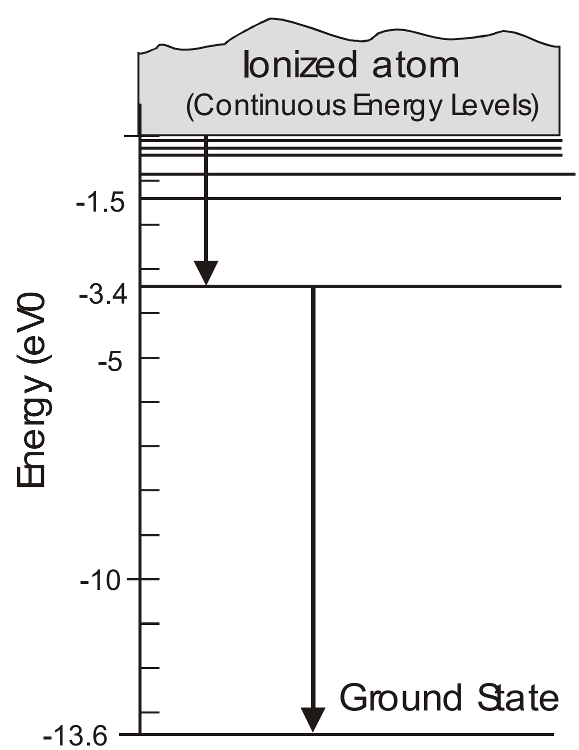
ii. The frequency that corresponds to this energy

$$E = hf \qquad f = \frac{E}{h} = \frac{3.4\ eV}{4.14\ x10^{-15}\ eV\cdot s} = \boxed{8.2\ x10^{14}\ Hz}$$

c. The following diagram shows some of the energy levels of the hydrogen atom, including those that are involved in the processes described above. Draw arrows on the diagram showing only the transitions involved in these processes.

d. The atom is in its ground state when a 15 eV photon interacts with it. All the photon's energy is transferred to the electron, freeing it from the atom. Determine the following.

i. The kinetic energy of the ejected electron.



$$E = E_{Photon} - E_{electron} = 15\ eV - 13.6\ eV$$

$$E = \boxed{1.4\ eV}$$

ii. The de Broglie wavelength of the electron.

$$K = \frac{1}{2}mv^2 \quad v = \sqrt{\frac{2K}{m}} \quad = \sqrt{\frac{2(1.4\ \cancel{eV})}{9.11\ x10^{-31}\ \cancel{kg}}\left(\frac{1.60\ x\,10^{-19}\ \frac{\cancel{kg}\cdot m^2}{s^2}}{1\ \cancel{eV}}\right)}$$

$$v = \sqrt{0.4618\ x\,10^{12}\ \frac{m^2}{s^2}} \quad = 0.6796\ x\,10^{6}\ \frac{m}{s} \quad = \quad 6.796\ x\,10^{5}\ \frac{m}{s}$$

$$\lambda = \frac{h}{p} \quad p = mv \quad so \quad \lambda = \frac{h}{mv} \quad = \frac{6.63\ x10^{-34}\ \frac{\cancel{kg}\cdot m^{\cancel{2}}}{\cancel{s}^{2}}\cdot \cancel{s}}{9.11\ x10^{-31}\ \cancel{kg}\left(6.796\ x\,10^{5}\ \frac{\cancel{m}}{\cancel{s}}\right)}$$

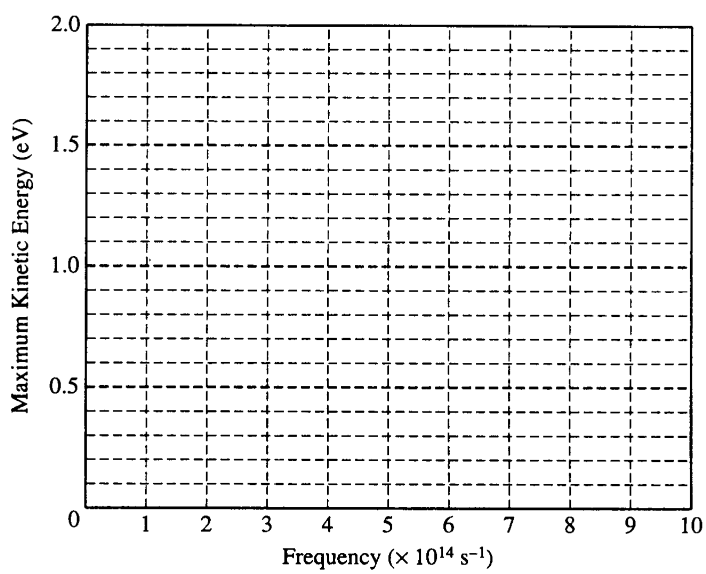
$$\lambda = 0.107\ x10^{-8}\ m \quad = \quad \boxed{1.07\ x10^{-9}\ m}$$

From 1994:

- A series of measurements were taken of the maximum kinetic energy of photoelectrons emitted from a metallic surface when light of various frequencies is incident on the surface.

  a. The table below lists the measurements that were taken. On the axes, plot the kinetic energy versus light frequency for the five data points given. Draw on the graph the line that is your estimate of the best straight-line fit to the data points.

Light Frequency (10^{14} s^{-1})	Maximum Kinetic Energy (electron volts)
5.00	0.10
6.00	0.45
7.00	0.95
8.00	1.30
9.00	1.45



b. From this experiment, determine a value of Planck's constant h in units of electron volt-seconds. Briefly explain how you did this.

Light Frequency (10^{14} s^{-1})	Maximum Kinetic Energy (electron volts)
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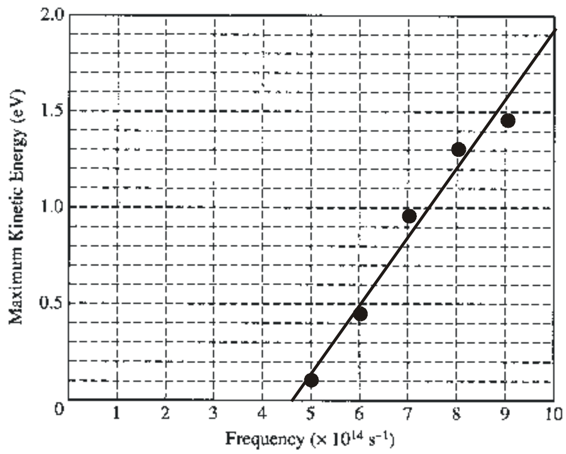


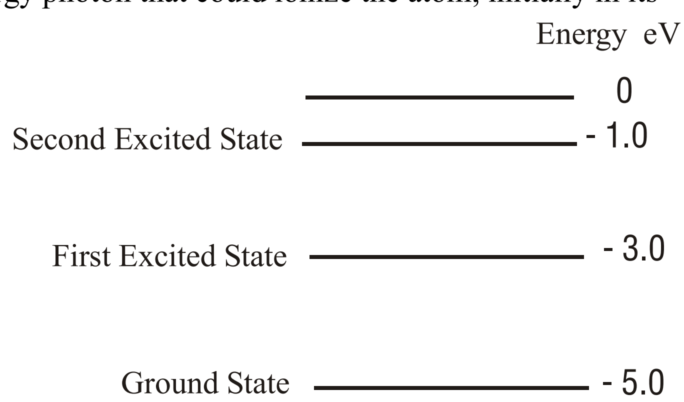
Plot the data points and obtain a curve. Then determine the slope of the curve.

$K_{\max} = hf - \phi$ *Equation for a line. h is the slope of the line.*

$$h = \frac{K_2 - K_1}{f_2 - f_1} = \frac{1.9\ eV - 0\ eV}{(10 - 4.6)\ x10^{14}\frac{1}{s}} = \boxed{3.6\ x10^{-15}\ eV \cdot s}$$

From 1985:

- An energy-level diagram for a hypothetical atom is shown to the right.
  a. Determine the frequency of the lowest energy photon that could ionize the atom, initially in its ground state.
  b. Assume the atom has been excited to the state at -1.0 electron volt.
     i. Determine the wavelength of the photon for each possible spontaneous transition.
     ii. Which, if any, of these wavelengths are in the visible range?

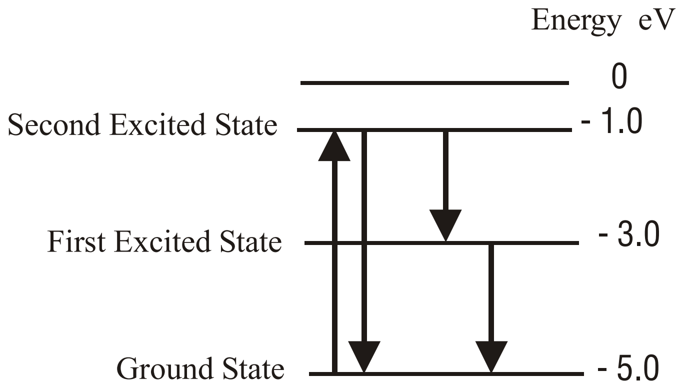


  c. Assume the atom is initially in the ground state. Show on the following diagram the possible transitions from the ground state when the atom is irradiated with electromagnetic radiation of wavelengths ranging continuously from 2.5×10^{-7} meter to 10.0×10^{-7} meter.

(a) The lowest energy photon that could ionize the atom would be one that kicks the electron to the 0 eV energy state. This would be an energy of – 5.0 eV.

$$E = hf \quad f = \frac{E}{h} = \frac{5.0\ e\cancel{V}}{4.14\ x10^{-15}\ e\cancel{V} \cdot s} = \boxed{1.21\ x10^{15}\ Hz}$$

(b) i. *Here is the diagram showing all possible transitions for the electron that has reached the second excited state:*



The possible energy transitions are:

$$-1.0\ eV - (-5.0\ eV) = 4.0\ eV$$

$$-1.0\ eV - (-3.0\ eV) = 2.0\ eV$$

$$-3.0\ eV - (-5.0\ eV) = 2.0\ eV$$

Now we can find the wavelength of the photons that have this energy:

$$E = hf \quad and \quad v = f\lambda \quad f = \frac{v}{\lambda} \quad plug\ in\ for\ f \quad E = h\left(\frac{v}{\lambda}\right) = \frac{hv}{\lambda}$$

$$E = \frac{hv}{\lambda} \quad \lambda = \frac{hv}{E} \quad \lambda = \frac{hc}{E} \quad v = c,\ right?$$

First transition:

$$\lambda = \frac{hc}{E} = 1.99\ x10^{-25}\ \cancel{J} \cdot m\left(\frac{1}{4.0\ e\cancel{V}}\right)\left(\frac{1\ e\cancel{V}}{1.60\ x10^{-19}\ \cancel{J}}\right) = 0.31\ x10^{-6}\ m$$

$$\lambda = 0.31\ x10^{-6}\ \cancel{m}\left(\frac{10^9\ nm}{1\ \cancel{m}}\right) = 0.31\ x10^{-3}\ nm = \boxed{310\ nm}$$

Second (and third) transition:

$$\lambda = \frac{hc}{E} = 1.99\ x10^{-25}\ \cancel{J} \cdot m\left(\frac{1}{2.0\ e\cancel{V}}\right)\left(\frac{1\ e\cancel{V}}{1.60\ x10^{-19}\ \cancel{J}}\right) = 0.622\ x10^{-6}\ m$$

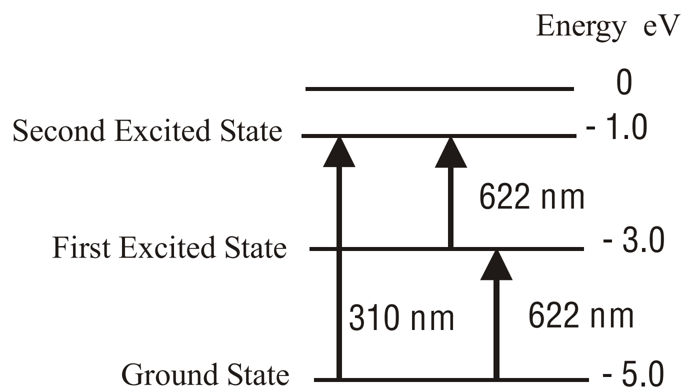
$$\lambda = 0.622\ x10^{-6} \cancel{m}\left(\frac{10^{9}\ nm}{1\ \cancel{m}}\right) = 0.622\ x10^{-3}\ nm = \boxed{622\ nm}$$

ii. Which, if any, of these wavelengths are in the visible range?

The second and third transitions; from – 1.0 eV to – 3.0 eV and from – 3.0 eV to – 5.0 eV.

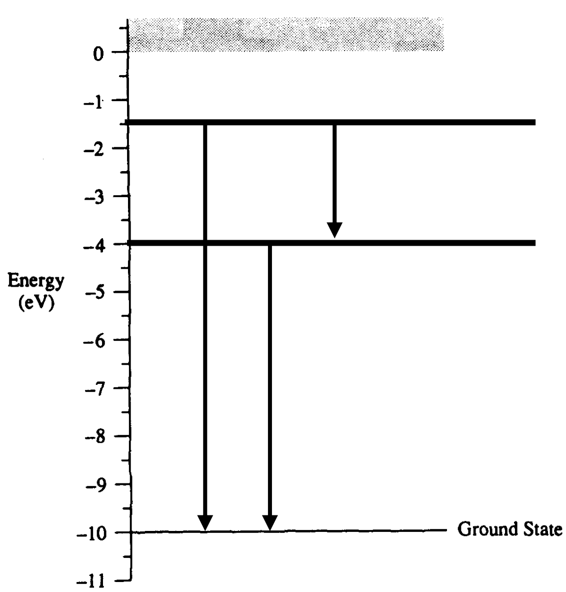
c. Assume the atom is initially in the ground state. Show on the following diagram the possible transitions from the ground state when the atom is irradiated with electromagnetic radiation of wavelengths ranging continuously from 2.5 x 10^{-7} meter to 10.0 x 10^{-7} meter.

The light incident on the atom would have a wavelength of 250 nm to 1000 nm. Wavelengths that would cause a transition would be at 622 nm and at 310 nm. The light needed to ionize the atom has a wavelength of 249 nm, the incident light is longer than that. So only the three transitions are possible.



From 1992:

- The ground-state energy of a hypothetical atom is at - 10.0 *eV*. When these atoms, in the ground state, are illuminated with light, only the wavelengths of 207 nanometers and 146 nanometers are absorbed by the atoms. (1 nanometer = 10^{-9} meter).



a. Calculate the energies of the photons of light of the two absorption-spectrum wavelengths.

$$E = \frac{hc}{\lambda} = \frac{1.24 \times 10^3\ eV \cdot \cancel{nm}}{207\ \cancel{nm}} = \boxed{5.99\ eV}$$

$$E = \frac{hc}{\lambda} = \frac{1.24 \times 10^3\ eV \cdot \cancel{nm}}{146\ \cancel{nm}} = \boxed{8.49\ eV}$$

b. Complete the energy-level diagram shown above for these atoms by showing all the excited energy states.

c. Show by arrows on the energy-level diagram all of the possible transitions that would produce emission spectrum lines.

d. What would be the wavelength of the emission line corresponding to the transition from the second excited state to the first excited state?

$$\Delta E = 8.49\ eV - 5.99\ eV = 2.5\ eV$$

$$E = \frac{hc}{\lambda} \quad \lambda = \frac{hc}{E} = \frac{1.24 \times 10^3\ \cancel{eV} \cdot nm}{2.5\ \cancel{eV}} = \boxed{496\ nm}$$

e. Would the emission line in (d) be visible? Briefly justify your answer.

Yes. The visible spectrum extends from 400 to 700 nm.