12 Quantum and Nuclear Physics review answers

Nuclear Physics

1. a) Define decay constant
The probability that an unstable nucleus will decay in a given time.

b) State the equation showing how activity of a radioactive source varies over time.
$A = \lambda N_0 e^{-\lambda t}$

c) Protactinium-234 half-life can be measured in the classroom because the protactinium salt dissolves in an organic layer above the stock solution. The decay constant for protactinium-234 = 0.010 s^{-1}. Calculate the time taken for the number of atoms of Protactinium-234 to halve.
$A = \lambda N_0 e^{-\lambda t}$.
At time t=0: $A = \lambda N_0$
If activity has halved $e^{-\lambda t}$ must equal 0.5. ($\lambda N_0 e^{-\lambda t} = 0.5 \lambda N_0$)
$0.5 = e^{-\lambda t} \Rightarrow \ln(0.5) = -\lambda t \Rightarrow t = -\ln(0.5)/-\lambda = -\ln(0.5)/0.010 = 69$ s

d) State the half-life of protactinium.
This is the answer to the previous question: note the "state" in the question: 69 s.

e) If the activity of a source is 44,800 Bq calculate the number of Protactinium-234 present.
$A = \lambda N_0 e^{-\lambda t}$ but t=0 so $A = \lambda N_0$
$N_0 = A/\lambda = 44{,}800 / 0.010 = 4.5\times10^6$ nuclei.

2. Geiger and Marsden performed an experiment firing alpha particles at a thin gold foil.
(a) Explain the conclusions that were drawn from this experiment and how they fit in with the Rutherford model of the atom that these results gave rise to.
Most of the alpha particles passed through the gold with little or no deflection so suggesting most of the structure is empty.
Some of the alpha particle rebounded strongly suggesting there are parts of the structure that repel the alpha particles and that these parts are signifivantly more massive than the alpha particle. (i.e. small but (relatively) massive positive parts)

(b) If an alpha particle has an initial velocity of 2×10^7 m/s and it rebounds from a gold nucleus (without touching it) what is the maximum radius of that gold nucleus?
$\mathbf{q}_{gold} = 79\times(1.6\times10^{-19})$ C
Closest approach calculation: Ek $\Rightarrow$ Ep at point of closest approach (for a particle travelling directly towards a nucleus).
$\frac{1}{2} m v^2 = k q q / r$ ($E_p = qV$)
$r = k q q / \frac{1}{2} m v^2 = 8.99\times10^9 \times 4\times(1.6\times10^{-19})\times79\times(1.6\times10^{-19}) / (0.5\times9.11\times10^{-31}\times(2\times10^7)^2) =$ 4.0×10^{-10}m

3. A more accurate way to measure nuclear diameters is to think of the particles as matter waves and realize that the nucleus that is interacting with the matter wave is causing diffraction. A beam of 80.0 MeV neutrons has de Broglie wavelength of 3.2×10^{-15} m and are diffracted upon passing through a thin lead foil. The first minimum in the diffraction pattern is measured at 12.6°. Estimate the diameter of the lead nucleus.

$\sin\theta = \lambda / D$

$D = \lambda / \sin\theta = 3.207\times10^{-15} / \sin 12.6° = 1.47\times10^{-14}$ m

Quantum Physics

1. (a) Which form of nuclear radiation have discrete energy levels?

Type of Radiation	Alpha particle (2 protons, 2 neutrons)	Beta particle (high speed electron or positron)	Gamma ray (high frequency electro-magnetic wave)
Energy levels	Discrete	Continuous	Discrete

2. (b) Explain why the fact that both B+ and B- spectra are continuous gives rise to the postulate of the existence of the neutrino.
If nuclei have discrete energy levels then there should be another particle to make the total energy released by beta decay discrete.

3. In Schrodinger's wave equation fits the boundary conditions of the three dimensions of the atom giving rise to both radial and angular allowed modes with discrete energy states. All you need to know is that the probability of finding an electron at a point is given by the square of the amplitude of the wave function gives the probability.

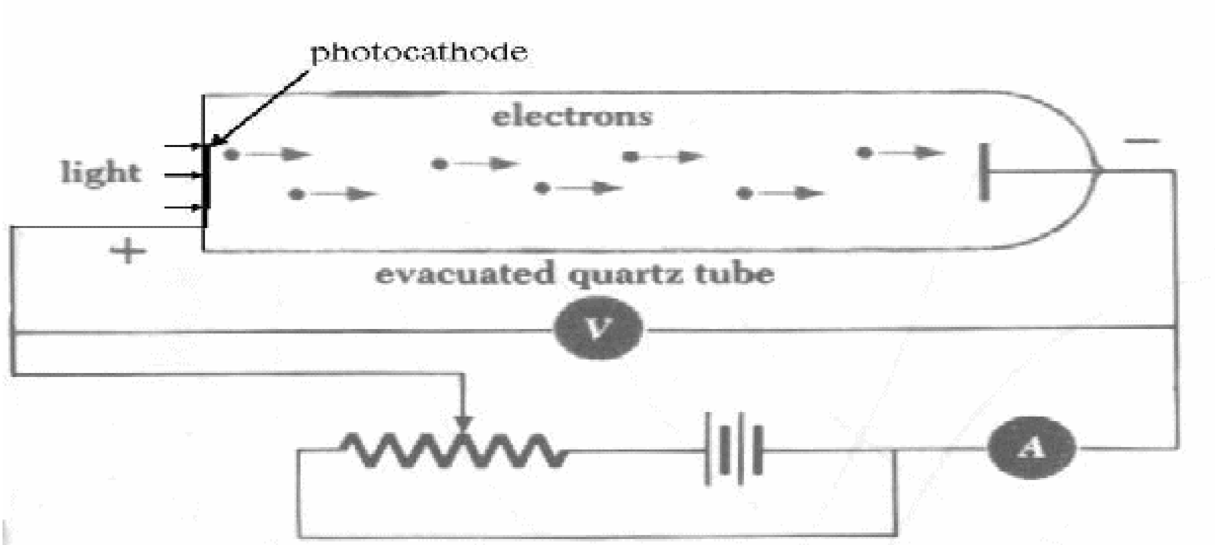
a. Why is the probability of finding an electron at a point as described by the Schrodinger equation always positive even if the Shrodinger equation can give negative values?
The probability of finding an electron is the square of the wave equation so is always positive.

b. What property of the electron remains undefined by the Schrodinger equation?
Position

4. Outline the Hesienberg uncertainty principle and use it to explain why knowing precisely the de Broglie wavelength of a particle means that its position is very uncertain.
There is a minimum uncertainty about pairs of properties of any particles. For example is the wavelength is known precisely then this means its momentum is also known, position is paired with momentum in the uncertainty principle so therefore is very uncertain if the wavelength is known precisely.

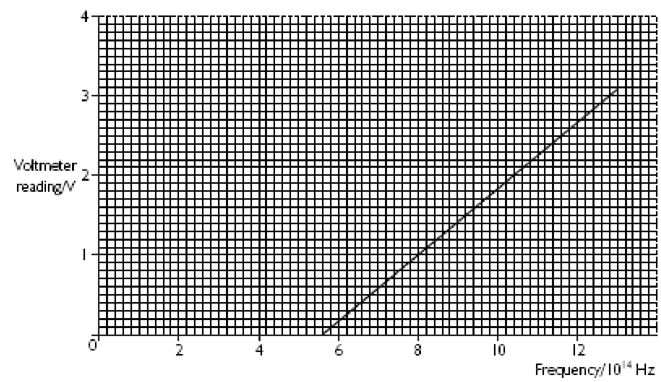
5. (a) Explain why the wave model of light does not account for the observation of the photoelectric effect (light causes electron leave a surface if the light is of a high enough frequency, the intensity does not change the ability of light to remove electrons from a surface) **If light was purely a wave then increasing the intensity should remove electrons.**

(b) How does the Einstein model of light explain the photo-electric effect? **Light is quantum and the amount of energy of each quanta of light (photon) depends on its frequency.**



(c) Using the apparatus above scientists can measure the stopping voltage needed to stop the photoelectrons causing a current. Draw a graph of stopping voltage against frequency and show what measurement can be used to determine the energy needed to ionize the photocathode.

The frequency for zero stopping potential (the x axis intercept) multiplied by plank's constant (the gradient) gives the energy needed to ionize the photocathode.
(or the absolute value of the y intercept)



6. In the Bohr model of the atom electrons orbit the nuclei in an approximately circular orbit.

a) Calculate the angular momentum with which the electron must orbit the proton for the ground state (n = 1) in the Bohr model of the hydrogen atom.

b) Calculate the velocity of the electron.

c) What is the radius of this ground state orbit?

a) Angular momentum = mvr = nh/2π
$= 1 \times 6.63 \times 10^{-34} / 2\pi = 1.06\times10^{-34}\ kgm^2s^{-1}$.

b) Centripetal force is provided by coulomb attraction:
$mv^2/r = kqq/r^2$……………….$mv^2r = kqq$……………….$v.mvr = kqq$
$v = kqq/mvr = 8.99 \times 10^9 x1.6x10\text{-}19x1.6x10^{-19}/1.06x10^{-34} = 2.17x10^6\ ms^{-1}$.

c) $r = mvr/mv = 1.06x10^{-34}/(9.110 \times 10^{-31}x2.17x10^6) = 5.4x10^{-11}m$