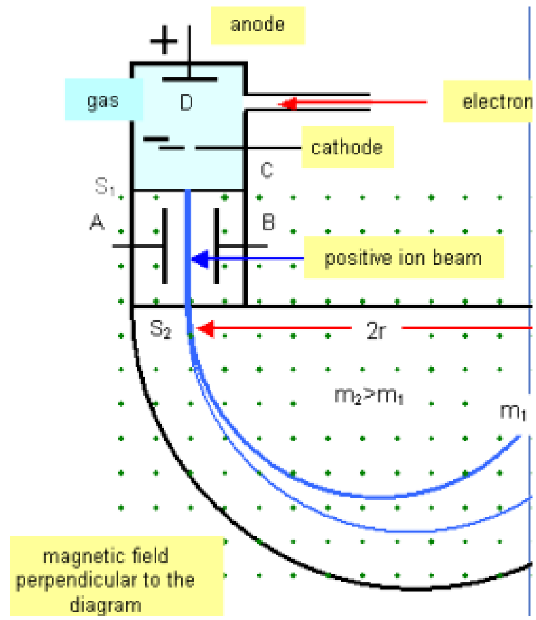
13 Quantum and Nuclear Physics review answers

Nuclear Physics



1. a) Describe how the masses of nuclei may be determined using a Bainbridge mass spectrometer by referring to the diagram on the right
b) Explain how the existence of isotopes is used as evidence for the existence of neutrons in the nucleus.

The different isotopes can be measured on the mass spectrometer and shown to have a different mass but the charge on the nucleus is the same (same chemistry as the other isotopes) there must therefore be a particle that has a mass of 1u and a charge of zero.

2. a) Define decay constant
b) State the equation showing how activity of a radioactive source varies over time.

$A = A_0 e^{-\lambda t}$

c) Derive the relationship between decay constant and half-life.

[Useful maths for this: $\ln(e^x) = x$, $\ln(1/x) = -\ln(x)$]

At $t = t_{1/2}$ the number of remaining nucleons is half the original so $N/N_o = 0.5$.
Or activity is halved so $A/A_o = 0.5$
$0.5 = e^{-\lambda t}$ ➔ $\ln(0.5)=-\lambda t$ ➔ $t = -\ln(0.5)/-\lambda = \ln(2)/\lambda$

d) Calculate the decay constant for protactinium-234 given that its half-life is approximately 70 seconds.

Flipping the relationship above $\lambda = \ln(2)/t_{1/2} = \ln(2)/70 = 0.010\text{s}^{-1}$.

e) Use this decay constant calculate the time taken for the activity of a protactinium source to reduce to 1% of its original level.

If acticity is 1% of original **$A/A_o = 0.01$**

$A = A_0 e^{-\lambda t}$ so $A/A_0 = e^{-\lambda t}$

$e^{-\lambda t} = 0.01$ **taking ln of both sides:**

$-\lambda t = \ln(0.01)$ **$\lambda = 0.010$ and $\ln(0.01) = 4.605$**

$t = 4.605/0.01 = 460\text{s}$

3. Explain Beta+ decay in terms of nucleon transformation.

In a nucleus a proton transforms into a neutron emitting a positron and a neutrino.

4. Geiger and Marsden performed an experiment firing alpha particles at a thin gold foil. 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?

$q_{gold} = 79\times(1.6\times10^{-19})$ C

Closest approach calculation: Ek ➔ Ep at point of closest approach (for a particle travelling directly towards a nucleus).

$\frac{1}{2} m v^2 = k q q / r$ (Ep = qV)

$r = k q q / \frac{1}{2} m v^2 = 8.99\times10^{9} \times 4\times(1.6\times10^{-19})\times79\times(1.6\times10^{-19}) / (0.5\times9.11\times10^{-31}\times(2\times10^{7})^2) = 4.0\times10^{-10}$ 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. (a) Explain how both absorption and emission spectra in elements provide evidence for the Bohr model of the atom and atomic energy levels.

Specific frequencies of electrons are absorbed/emitted therefore the atoms are absorbing/emitting discrete amounts of energy as their energy levels change.

(b) Describe an experiment to observe emission spectra.

Electricity is passed through a tube containing a gas at low pressure. And the resulting light viewed through a spectrometer.

(c) Outline an experiment (Davisson-Germer) that demonstrated de Broglie wavelengths in electrons

An electron beam is directed at a crystal structure of known layer separation and the interference pattern is observed by detecting the amount of electrons reflecting at different angles.

(d) If an electron is confined to a box of length L it will form a standing wave

(i) What is wavelength of the standing wave of lowest (zeroeth) energy level? **2L**

(ii) What is the general formula for wavelength of the standing wave of energy level n?

$\lambda = 2L/n$

(iii) Show that the kinetic energy of such an electron is $n^2h^2/(8m_eL^2)$

$$p = \frac{h}{\lambda} = \frac{nh}{2L} \quad \text{where } n = 1,2,3,4 \ldots$$

$$\frac{1}{2}mv^2 = \frac{p^2}{2m} = \frac{n^2h^2}{8mL^2} = E_n$$

Energy for nth quantum state for particle in infinite box.

(e) Determine the wavelength of the photons emitted by a Hydrogen atom when the electron moves from:

(i) n=2 state with an energy level of -3.4eV to its ground state of n=1 with an energy level of -13.6eV?

E = hf ..with E in Joules… so f=E/h = (13.6-3.4)x1.6x10^{-19}/6.63x10^{-34} = 2.46x10^{15}m.

(ii) n=4 state with an energy level of -0.8eV to its ground state of n=2 with an energy level of -3.4eV?

f=E/h = (3.4-0.8)x1.6x10^{-19}/6.63x10^{-34} = 6.76x10^{14}m.

4. 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?

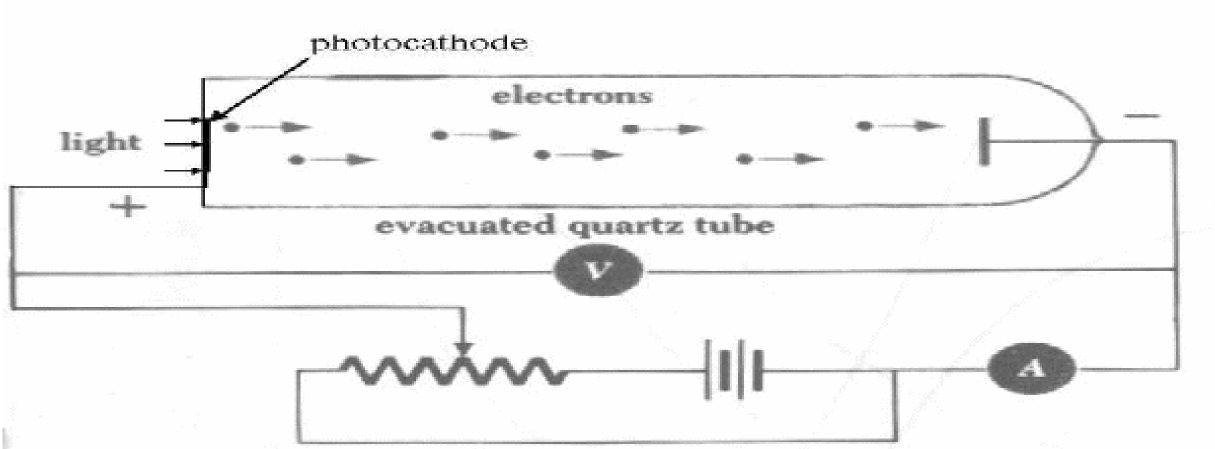
The probability of finding an electron is the square of the wave equation so is always positive.

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

5. 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.**

6. (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)