Wallace Hall Academy

Cfe Higher Physics

Particles and Waves

Exam Questions Part 1: Solutions

PARTICLES AND WAVES - EXAM QUESTIONS PART 1

SECTION 1 - THE STANDARD MODEL

1) Alpha particles are positively charged. It was concluded that electrostatic repulsion from a like charge of very large mass was required to produce the observed large deviations in path. However, most alpha particles were undeflected and this led Rutherford to conclude that the atom was mostly empty space with a very large positive mass at the centre.

2a) The number of alpha particles detected at X is much greater than detected at Y. Almost all are detected at X.

b) Any <u>three</u> from:

- Small nucleus compared to size of atom
- Most of atom is empty space.
- Mass concentrated in nucleus
- Nucleus is positively charged.

Note: Massive nucleus
Small nucleus

3a) 2 Up + 1 down = proton

Charge: $(2 \times +\frac{2}{3}e) + (1 \times -\frac{1}{3}e) = +e$

or

Baryon: $(2 \times +\frac{1}{3}) + (1 \times +\frac{1}{3}) = 1$

b) Down quark + Anti-up quark

4a) $\bar{u} = -\frac{2}{3}e$, $K^- = -e$

$s \rightarrow -\frac{1}{3}e$

b) By conservation of charge:

Charge of $K^- = (-\frac{2}{3}) + (-\frac{1}{3}) = -1e$
Charge of $p = +1e$
Total $= \underline{0}$

$\Rightarrow$ Since the neutron has 0 charge, X must have zero charge and be neutral.

c) X is a meson. As K^- is a meson (2 quarks) and proton is a baryon (3 quarks), and neutron is a baryon (3 quarks) then X must have 2 quarks.

5a) (i) n – neutron, 1 UP and 2 DOWN
p – proton, 2 UP and 1 DOWN

β^- – beta (electron), N/A
$\bar{\nu}$ – antineutrino, N/A.

(ii) $p \rightarrow n + \beta^+ + \nu$

(iii) Weak interaction

b i) anti-proton
anti-electron (positron)

(ii) Neutral

(iii) They would annihilate with atoms of hydrogen very quickly.

bai) $^{206}_{82}Pb$

(ii) electrons

bi) 2 up + 1 down = proton

$(2 \times +\frac{2}{3}e) + (1 \times -\frac{1}{3}e) = \underline{\underline{+1e.}}$

(ii) In high energy collisions using particle accelerators.

(iii) Exactly the same in all ways except the charge is opposite.

7a) Baryon – 3 quarks

Meson – 2 quarks (a quark and antiquark pair).

bi) Charge

(ii) $u + u + d + \bar{s} + d$

$\Rightarrow \frac{2}{3}e + \frac{2}{3}e + (-\frac{1}{3}e) + (+\frac{1}{3}e) + (-\frac{1}{3}e)$

$\Rightarrow$ Charge $= +\frac{3}{3}e = +1e$.

(iii) $X = +1e$

(iv) 2 Up + 1 down

$(2 \times +\frac{2}{3}e) + (1 \times -\frac{1}{3}e) = +1e$

SECTION 2 – FORCES ON CHARGED PARTICLES

(1) a) E_k at plate A $= \frac{1}{2}mv^2$

$= \frac{1}{2} \times 6.64 \times 10^{-27} \times (2.60 \times 10^{6})^2$

$= 2.24 \times 10^{-14}$ J

$\Rightarrow E_w = 3.05 \times 10^{-14} - 2.24 \times 10^{-14}$

$= \underline{\underline{8.1 \times 10^{-15} \text{ J}}}$

b) $E_w = QV$

$8.1 \times 10^{-15} = 3.20 \times 10^{-19} \times V$

$V = \dfrac{8.1 \times 10^{-15}}{3.20 \times 10^{-19}}$

$= \underline{\underline{25.3 \text{ kV}}} \quad (2.53 \times 10^{4} \text{ V})$

c) Since $E_w = QV$ and V is constant, then as Q of electron is smaller then E_w will be smaller.
This means E_k will be <u>smaller</u>.

Note (mass has no bearing on E_k).

2a) $E_w = E_k$
$= QV$
$= 1.6 \times 10^{-19} \times 25 \times 10^{3}$
$= \underline{\underline{4.0 \times 10^{-15}\ J}}$

b) Total E_k at B $= 4.0 \times 10^{-15} + 1.3 \times 10^{-16}$
$= 4.13 \times 10^{-15}\ J.$

$E_k = \frac{1}{2} m v^2$
$4.13 \times 10^{-15} = 0.5 \times 1.673 \times 10^{-27} \times v^2$

$v^2 = 4.937 \times 10^{12}$
$v = \sqrt{4.937 \times 10^{12}}$
$= \underline{\underline{2.22 \times 10^{6}\ ms^{-1}}}$

c) $E_w = Fd$

$4.0 \times 10^{-15} = F \times 1.2$

$F = \frac{4.0 \times 10^{-15}}{1.2}$
$= \underline{\underline{3.33 \times 10^{-15}\ N}}$

3(a) 200000 J of energy transfered to each coulomb of charge.

(b) Protons have a positive charge AND are attracted towards the negative plate / experience a force when in an electric field.

(c) (i) $E_w = QV$
$= 1.6 \times 10^{-19} \times 200 \times 10^{3}$
$= \underline{\underline{3.2 \times 10^{-14}}}$ J.

(ii) $E_k = \frac{1}{2} m v^2$
$3.2 \times 10^{-14} = \frac{1}{2} \times 1.673 \times 10^{-27} \times v^2$

$v^2 = 3.825 \times 10^{13}$
$v = \sqrt{3.825 \times 10^{13}}$
$= \underline{\underline{6.2 \times 10^{6} \text{ ms}^{-1}}}$

(d) No effect since QV are constant / unchanged (and $E_w = QV = E_k$)

4) $E_k = E_w$

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

$\frac{1}{2} \times 9.11 \times 10^{-31} \times v^2 = 1.6 \times 10^{-19} \times 2.5 \times 10^3$

$v^2 = \frac{1.6 \times 10^{-19} \times 2.5 \times 10^3}{\frac{1}{2} \times 9.11 \times 10^{-31}}$

$= 8.78 \times 10^{14}$

$v = \sqrt{8.78 \times 10^{14}}$

$= \underline{\underline{2.96 \times 10^7 \ ms^{-1}}}$

5) ai) $E_k = \frac{1}{2}mv^2$

$= \frac{1}{2} \times 9.11 \times 10^{-31} \times (4.2 \times 10^7)^2$

$= \underline{\underline{8.0 \times 10^{-16} \ J}}$

a ii) $E_w = E_k$

$E_k = QV$

$8.0 \times 10^{-16} = 1.6 \times 10^{-19} \times V$

$V = \frac{8.0 \times 10^{-16}}{1.6 \times 10^{-19}}$

$= 5000$

$= \underline{\underline{5kV}}$ $(5 \times 10^3 V)$

b) Plate P must be positive.
Plate Q must be positive and twice the voltage of P. 9

6) a) $E_K = E_W$

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

$\frac{1}{2} \times 9.11 \times 10^{-31} \times v^2 = 1.6 \times 10^{-19} \times 2.40 \times 10^3$

$$v^2 = \frac{1.6 \times 10^{-19} \times 2.40 \times 10^3}{\frac{1}{2} \times 9.11 \times 10^{-31}}$$

$$= 8.43 \times 10^{14}$$

$$v = \sqrt{8.43 \times 10^{14}}$$

$$= 2.90 \times 10^7 \ ms^{-1}$$

bi) It enters the plate with a horizontal velocity and this will remain constant throughout as there is no unbalanced force horizontally. The electric field applies a vertical unbalanced force upwards resulting in an acceleration upwards. The combination causes the path to be curved.

(ii) No unbalanced force at all so continues in straight line at constant speed.

c) As V_a increased, $E_W = E_k$ increased

⇒ v_H increases

⇒ Time between plates decreases,

⇒ Upwards deflection decreases

⇒ Length of scanned section decreases.

7a) $E_k = E_w$

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

$\frac{1}{2} \times 1.673 \times 10^{-27} \times v^2 = 1.6 \times 10^{-19} \times 2 \times 10^3$

$$v^2 = \frac{1.6 \times 10^{-19} \times 2 \times 10^3}{\frac{1}{2} \times 1.673 \times 10^{-19}}$$

$$= 3.83 \times 10^{11}$$

$$v = \sqrt{3.83 \times 10^{11}}$$

$$= \underline{\underline{6.19 \times 10^5 \ ms^{-1}}}$$

b) Field "into page".

c) $E_k(\text{final}) = E_k(\text{initial}) + qV$

$\frac{1}{2}mv^2 = \left[\frac{1}{2} \times 1.673 \times 10^{-27} \times (6.19 \times 10^5)^2\right] + \left[1.6 \times 10^{-19} \times 2 \times 10\right.$

$\frac{1}{2}mv^2 = 6.405 \times 10^{-16} \ J$

$$v^2 = \frac{6.405 \times 10^{-16}}{\frac{1}{2} \times 1.673 \times 10^{-27}}$$

$$= 7.657 \times 10^{11}$$

$$v = \sqrt{7.657 \times 10^{11}}$$

$$= \underline{\underline{8.75 \times 10^5 \ ms^{-1}}}$$

8a) Positive.

b) Component of velocity parallel to magnetic field is unchanged as no unbalanced force.

Component of velocity perpendicular to magnetic field causes circular motion.

c) Enter towards poles
and travel in spiral paths
or never reach the atmosphere
above the equator

Section 3 – Nuclear Reactions

1a) No. of neutrons $= 241 - 95$
$= \underline{\underline{146}}$

b) (i) $r = 95 - 2$
$= \underline{\underline{93}}$

{since $^{4}_{2}\alpha$}

$s = 241 - 4$
$= \underline{\underline{237}}$

(ii) Neptunium

B

2a) $r = (235 + 1) - (139 + 2 + 0)$
$= \underline{\underline{95}}$

$s = 92 - (57 + 42)$
$= -7$

$\Rightarrow s = \underline{\underline{7}}$

(b) Total mass before is greater then total mass after.
This loss in mass is due to it being converted into energy according to $E=mc^2$.

c) Total mass before $= 390.173 \times 10^{-27}$
$+ \; 1.675 \times 10^{-27}$
391.848×10^{-27} kg

Total mass after $= 230.584 \times 10^{-27}$
157.544×10^{-27}
1.675×10^{-27}
$+ \; 1.675 \times 10^{-27}$
391.478×10^{-27} kg

$\Rightarrow \Delta m = (391.848 - 391.478) \times 10^{-27}$
$= 0.37 \times 10^{-27}$ kg

$E = mc^2$
$= 0.37 \times 10^{-27} \times (3 \times 10^8)^2$
$= \underline{\underline{3.33 \times 10^{-11} \text{ J}}}$

3a) Induced – A neutron { is added / fired in / on left hand side of equation.

b) $r = (92 + 0) - (37 + (4 \times 0))$

$r = \underline{\underline{55}}$

$s = (235 + 1) - (137 + (4 \times 1))$

$s = \underline{\underline{95}}$

c) Americium

d) Mass befoe $= 390.219 \times 10^{-27}$

$+ \ 1.675 \times 10^{-27}$

391.894×10^{-27} kg

Mass after $= 227.292 \times 10^{-27}$

157.562×10^{-27}

$+ (4 \times) 1.675 \times 10^{-27}$

391.554×10^{-27} kg

$\Delta m = (391.894 - 391.554) \times 10^{-27}$

$= 0.34 \times 10^{-27}$ kg

$E = mc^2$

$= 0.34 \times 10^{-27} \times (3 \times 10^8)^2$

$= \underline{\underline{3.06 \times 10^{-11} \text{ J}}}$

4a i) Number of protons.

(ii) Number of protons and neutrons.

b) The neutrons released collide with other uranium nuclie causing these to split. This releases more nuetrons and the process repeats.

c) Mass before $= 390.173 \times 10^{-27}$
$+ \; 1.675 \times 10^{-27}$
391.848×10^{-27} kg

Mass after $= 232.242 \times 10^{-27}$
155.884×10^{-27}
1.675×10^{-27}
$+ \; 1.675 \times 10^{-27}$
391.476×10^{-27} kg.

$\Delta m = (391.848 - 391.476) \times 10^{-27}$
$= 0.372 \times 10^{-27}$ kg

$E = mc^2$
$= 0.372 \times 10^{-27} \times (3 \times 10^8)^2$
$= 3.35 \times 10^{-11}$ J

5) a) $x = 226 - 4$
$= \underline{222}$

$y = 88 - 2$
$= \underline{86}$

$\left[{}^{222}_{86}Rn \right]$

b) The mass of the products is less than the mass of the Radium nucleus. This mass loss is converted to energy.

c) Mass before $= 3.75428 \times 10^{-25}$ kg

Mass after $= 3.68771 \times 10^{-25} + 6.64832 \times 10^{-27}$
$= 3.7541932 \times 10^{-25}$ kg

$\Delta m = 3.75428 \times 10^{-25} - 3.7541932 \times 10^{-25}$
$= 8.68 \times 10^{-30}$ kg

$\Rightarrow E = mc^2$
$= 8.68 \times 10^{-30} \times (3 \times 10^8)^2$
$= \underline{7.812 \times 10^{-13} J}$

6a) Two nuclei are joining together therefore FUSION reaction.

b) The mass of the products is less than the mass of the reactants. This mass loss is converted into energy in accordance with $E = mc^2$.

7a) Nuclear Fusion reaction.

b) The total mass of the products on the RHS are less than the total mass of the reactants on the LHS. This loss of mass is converted into energy in accordance with $E=mc^2$, where m is the mass difference and c is the speed of light.

c) Mass before $= 5.00890 \times 10^{-27} + 3.34441 \times 10^{-27}$
$= 8.35331 \times 10^{-27}$ kg

Mass after $= 6.64632 \times 10^{-27} + 1.67490 \times 10^{-27}$
$= 8.32122 \times 10^{-27}$ kg

$\Delta m = 8.35331 \times 10^{-27} - 8.32122 \times 10^{-27}$
$= 3.209 \times 10^{-29}$ kg

$E = mc^2$
$= 3.209 \times 10^{-29} \times (3 \times 10^8)^2$
$= 2.8881 \times 10^{-12}$ J

d) Number of reactions $= \frac{\text{Energy per second}}{\text{energy per reaction}}$

$= \frac{25 \times 10^6}{2.8881 \times 10^{-12}}$

$= 8.658 \times 10^{18}$ reactions

Section 4 – Wave-particle Duality

1a i) $E_k = hf - hf_0$

$= 5.23 \times 10^{-19} - 2.56 \times 10^{-19}$

$= 2.67 \times 10^{-19}$ J

(ii) $E_k = \frac{1}{2} m v^2$

$2.67 \times 10^{-19} = \frac{1}{2} \times 9.11 \times 10^{-31} \times v^2$

$v^2 = \dfrac{2.67 \times 10^{-19}}{\frac{1}{2} \times 9.11 \times 10^{-31}}$

$= 5.86169045 \times 10^{11}$

$v = \sqrt{5.86169045 \times 10^{11}}$

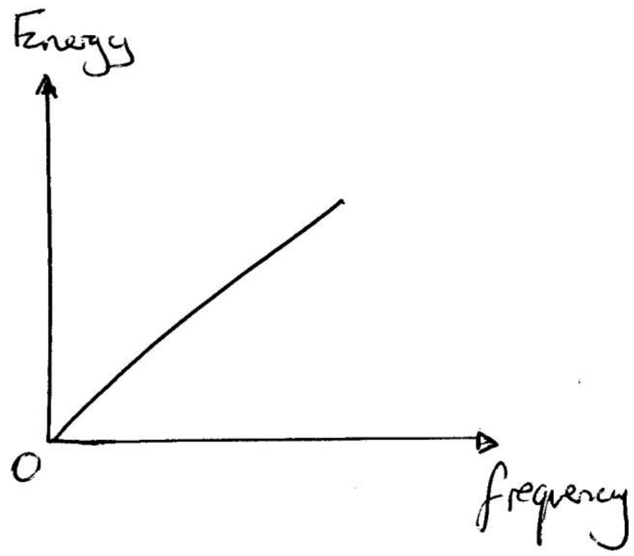
$v = 7.66 \times 10^5 \text{ ms}^{-1}$

b) The energy recieved by each electron has not changed as energy of photon has not changed

⇒ Kinetic energy gained does not change

⇒ speed does not change.

2 a)



$$\left[E = hf \Rightarrow E \propto f \right]$$

b) $E_k = hf - (hf_0)$

$6.0 \times 10^{-20} = (6.63 \times 10^{-34} \times 6.1 \times 10^{14}) - (hf_0)$

$6.0 \times 10^{-20} = 4.0443 \times 10^{-19} - (hf_0)$

$\Rightarrow (hf_0) = 4.0443 \times 10^{-19} - 6.0 \times 10^{-20}$

$= 3.4443 \times 10^{-19}$

$= \underline{\underline{3.44 \times 10^{-19} \text{ J}}}$.

c) Energy of photons unchanged

$\Rightarrow$ Kinetic energy gained unchanged.

3a) $v = f\lambda$

$3 \times 10^8 = f \times 605 \times 10^{-9}$

$f = \frac{3 \times 10^8}{605 \times 10^{-9}}$

$= 4.96 \times 10^{14}$ Hz

$W = hf_0$

$= 6.63 \times 10^{-34} \times 4.96 \times 10^{14}$

$= 3.29 \times 10^{-19}$ J

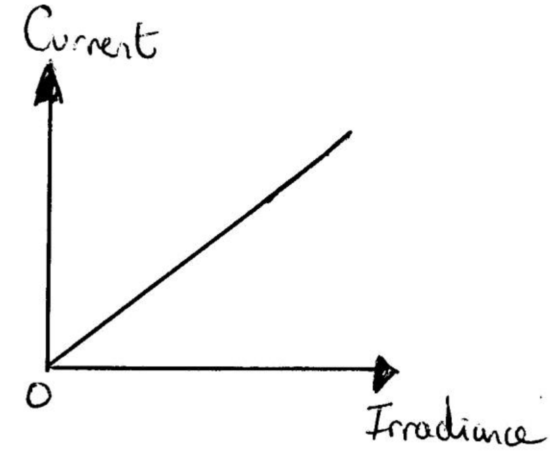
b) i) $E_{K(max)} = 5.12 \times 10^{-19} - 3.29 \times 10^{-19}$

$= 1.83 \times 10^{-19}$ J.

(ii) The Ammeter reading / Current will decrease.

As irradiance decreases, the number of photons hitting plate each second decreases therefore fewer electrons released each second.

4) a)



[$I \propto$ Irradiance]

b) (i) $v = f\lambda$

$3\times10^{8} = f \times 400\times10^{-9}$

$f = \frac{3\times10^{8}}{400\times10^{-9}}$

$= 7.5\times10^{14}$ Hz

$\Rightarrow E = hf$

$= 6.63\times10^{-34} \times 7.5\times10^{14}$

$= 4.97\times10^{-19}$ J.

$\Rightarrow E_k = 4.97\times10^{-19} - 3.11\times10^{-19}$

$= 1.86\times10^{-19}$ J

(ii) Some electrons may still have enough kinetic energy to travel from the plate to the cylinder.

5a) Threshold frequency.

b) (i) $E = hf_0$

$= 6.63 \times 10^{-34} \times 3.33 \times 10^{14}$

$= \underline{\underline{2.21 \times 10^{-19}}}$ J

(ii) $E = hf$

$= 6.63 \times 10^{-34} \times 5.66 \times 10^{14}$

$= 3.75 \times 10^{-19}$ J

$\Rightarrow E_k = (hf) - (hf_0)$

$= 3.75 \times 10^{-19} - 2.21 \times 10^{-19}$

$= \underline{\underline{1.54 \times 10^{-19}}}$ J

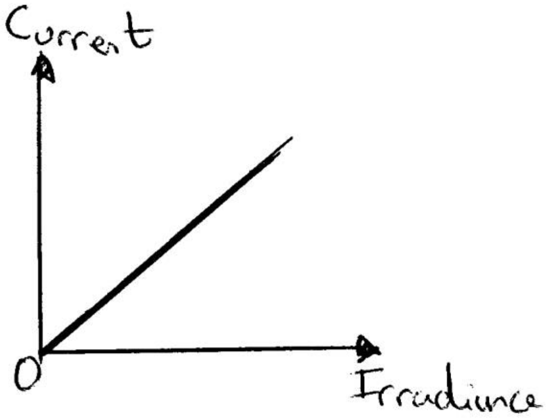
(iii) E_k gained $= E_w$

$= QV$

$= 1.6 \times 10^{-19} \times 2.00 \times 10^{4}$

$= \underline{\underline{3.2 \times 10^{-15} \text{ J}}}$

6a) (i)



(ii) Each photon is absorbed by a single electron. The energy of the photon is determined by $E = hf$, so if the frequency decreases below a certain level, the energy will be insufficient to eject the electron from the surface so current will be zero.

b i) The straight line should be extrapolated down to the x-axis. The x-axis intercept is the threshold frequency

x-axis intercept $= f_0 = \underline{6.7 \times 10^{14}}$ Hz

(ii) $W = hf_0$
$= 6.63 \times 10^{-34} \times 6.7 \times 10^{14}$
$= 4.44 \times 10^{-19}$ J.

$\Rightarrow$ Calcium

7a) The minimum energy required by an electron to escape an atom. This is absorbed from the incident photon.

b) (i) $E = hf$

$= 6.63 \times 10^{-34} \times 6.1 \times 10^{14}$

$= 4.04 \times 10^{-19}\ J$.

$E_k = (hf) - (hf_0)$

$= 4.04 \times 10^{-19} - 3.04 \times 10^{-19}$

$= \underline{1.00 \times 10^{-19}\ J}$

(ii) E_k gained $= QV$

$= 1.6 \times 10^{-19} \times 0.80$

$= 1.28 \times 10^{-19}\ J$

$\Rightarrow E_k\ (\text{TOTAL}) = 1.28 \times 10^{-19} + 1.00 \times 10^{-19}$

$= \underline{2.28 \times 10^{-19}\ J}$

c) Work done by field = Max kinetic energy after photon absorption

$QV = 1.00 \times 10^{-19}$

$V = \dfrac{1.00 \times 10^{-19}}{Q}$

$= \dfrac{1.00 \times 10^{-19}}{1.6 \times 10^{-19}}$

$= \underline{0.625\ V}$