Exam Practise 6 Short Answer

Q and A

Q1

A ball of mass 0.20 kg falls vertically and hits the ground at a velocity of 4.2 m s^{-1}. It rebounds vertically at an initial speed of 3.4 m s^{-1}.

(a) Calculate the change of momentum of the ball. **(3 marks)**

Taking downward as positive:

$mu = 0.20 \times 4.2 = 0.84\ \text{kg m s}^{-1}$

$mv = -0.20 \times 3.4 = -0.68\ \text{kg m s}^{-1}$

$\Delta p = mv - mu = -0.68 - 0.84$

$= -1.52\ \text{kg m s}^{-1}$

(b) What is the impulse applied to the ball by the ground? **(1 mark)**

Impulse = change of momentum

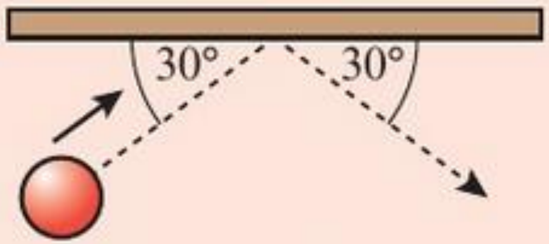
= −1.52 N s upwards

(c) The average force exerted on the ball while it was in contact with the ground was 18.0 N. Calculate the contact time. **(2 marks)**

Impulse $= F\Delta t$ so $\Delta t = \dfrac{1.52}{18} = 0.084\ \text{s}$ (2 s.f.)

Q2

A football of mass m is kicked against a wall. It approaches the wall at speed v and rebounds at the same speed as shown below.

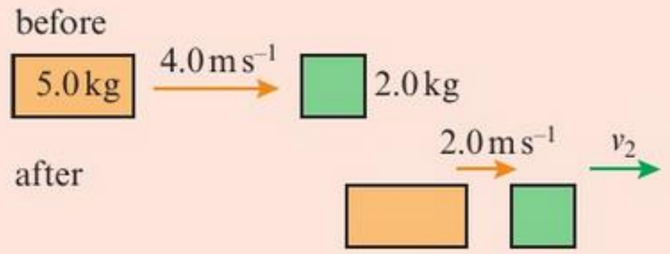


Use the law of conservation of momentum to explain why the ball rebounds at the same angle. **(3 marks)**

Each component of momentum is conserved. The component parallel to the surface of the wall is $mv\cos\theta$. m and v are unchanged by the collision so θ must be the same too.

Q3

The diagrams show two objects before and after a collision.



(a) Calculate the final velocity of the 2.0 kg mass. **(2 marks)**

Momentum is conserved:

$m_1 u = m_1 v_1 + m_2 v_2$

Rearranging: $v_2 = \frac{(m_1 u - m_1 v_1)}{m_2}$

$v_2 = \frac{5.0 \times 4.0 - 5.0 \times 2.0}{2.0} = 5.0\,\mathrm{m\,s^{-1}}$

(b) Determine whether or not this collision is elastic. **(3 marks)**

If the collision is elastic, kinetic energy will be conserved.

$E_{K\ before} = \frac{1}{2} m_1 u^2 = \frac{1}{2} \times 5.0 \times 4.0^2 = 40\,\mathrm{J}$

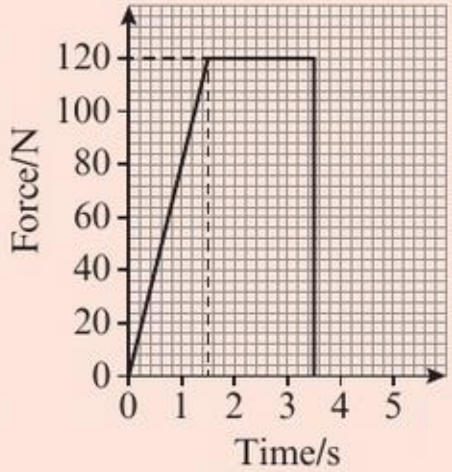
$E_{K\ after} = \frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2$

$= \frac{1}{2} \times 5.0 \times 2.0^2 + \frac{1}{2} \times 2.0 \times 5.0^2 = 35\,\mathrm{J}$

$E_{K\ after} < E_{K\ before}$ so some KE has been transferred to heat and sound (5.0 J). This is an inelastic collision.

Q4

A man pushes a child on a sledge along horizontal snow with a force that varies in the way shown in the figure. The sledge is initially at rest. The man stops pushing after 3.5 s and lets it slide away. The frictional drag from the snow is negligible. The total mass of the sledge and child is 75 kg.



(a) State the physical quantity represented by the area under the graph and give its correct SI unit. **(1 mark)**

Impulse (or change of momentum).
SI unit is N s or kg m s^{-1}.

(b) Calculate the velocity of the sledge at the moment the man stops pushing. **(4 marks)**

impulse = change of momentum
= area under graph.

area $= \frac{1}{2} \times 120 \times 1.5 + 120 \times 2.0 = 330$ N s

$m\Delta v = 330$ so $\Delta v = \frac{330}{75} = 4.4$ m s^{-1}

Since $u = 0$, the final velocity is 4.4 m s^{-1}.

(c) Later, when the same child and sledge is sliding over horizontal snow at 4.0 m s^{-1}, a second child of mass 45 kg runs in the same direction at 6.0 m s^{-1} and jumps onto the moving sledge.

(i) Calculate the velocity of the sledge with two children just after the second child lands on it. **(2 marks)**

momentum is conserved so:

$75 \times 4.0 + 45 \times 6.0 = 570 = (75 + 45)v$

$v = \frac{570}{120} = 4.75 = 4.8$ m s^{-1} to 2 s.f.

(ii) State whether this is an elastic or inelastic collision and justify your answer by calculation. **(3 marks)**

KE before $= \frac{1}{2} \times 75 \times 4.0^2 + \frac{1}{2} \times 45 \times 6.0^2$
$= 1410$ J

KE after $= \frac{1}{2} \times 120 \times 4.75^2 = 1354$ J

There is a small difference in KE before and after. It is not conserved in the collision so the collision is inelastic.

Q5

1 An electron and a proton are both accelerated through a potential difference of 2000 V.

(a) Calculate the energy gained in each case and express your answer in both electronvolts and joules. **(3 marks)**

Both gain the same energy because both have a single charge e and are accelerated through the same p.d. Energy gained = 2000 eV (2 keV). Converting to joules:

$$2000\,\text{eV} = 2000 \times 1.60 \times 10^{-19}$$
$$= 3.2 \times 10^{-16}\,\text{J}$$

Q6

A kettle contains 0.80 kg of water at 25°C. Calculate the minimum amount of energy needed to:

(a) Raise the temperature of the water to 100°C. **(2 marks)**

To raise temperature with no change of state we use the specific heat capacity.

$\Delta E = mc\Delta\theta = 0.80 \times 4200 \times 75$

$= 250\,000$ J (2 s.f.)

(b) Change the state of all of the water from a liquid to a gas at 100°C. **(2 marks)**

To change the state of the water at its boiling point we use the specific latent heat of vaporisation.

$\Delta E = L\Delta m = 2\,260\,000 \times 0.80$

$= 1\,800\,000$ J (2 s.f.)

Q7

1 Convert the following temperatures to the Kelvin scale:

(a) a room temperature of about 21°C **(1 mark)**

$T = 21 + 273 = 294\,K$

(b) the boiling point of water at 100°C. **(1 mark)**

$T = 100 + 273.15 = 373.15\,K$

2 Convert the following temperatures to the Celsius scale:

(a) the temperature of empty space, 2.7 K **(1 mark)**

$\theta = 2.7 - 273.15 = -270.5°C$

(b) The temperature at the surface of the Sun, 5800 K. **(1 mark)**

$\theta = 5800 - 273 = 5527°C$

Q8

Iron-56 has 26 protons and (56 − 26) = 30 neutrons in the nucleus. Use the data below to calculate the nuclear binding energy of the iron-56 nucleus and give your answer in J and MeV.

- atomic mass of iron-56 = 55.934939 u
- mass of an electron m_e = 0.000549 u
- mass of a proton m_p =1.007276 u
- mass of a neutron m_n =1.008665 u **(5 marks)**

Nuclear mass
= (55.934938 − 26 × 0.000549) u
= 55.920664 u

Mass of separated nucleons
= (26 × 1.007276 + 30 × 1.008665) u
= 56.449126 u

Δm = (56.449126 − 55.920664) u
Δm = 0.528462 u

B.E.
= $9.00 \times 10^{16} \times 0.528462 \times 1.66 \times 10^{-27}$
= 7.90×10^{-11} J or 493 MeV (3 s.f.)

Q9

Estimate the total energy that could be released from 1 kg of uranium-235 by the nuclear fission reaction yielding ${}^{90}_{36}K$ and ${}^{144}_{56}Ba$. Assume that 1 kg ${}^{235}U$ contains 2.56×10^{24} atoms. **(4 marks)**

$m_U = 235.043930\,u$ $\quad$ $m_{Kr} = 89.919517\,u$
$m_{Ba} = 143.922953\,u$ $\quad$ $m_n = 1.008665\,u$
$u = 1.66 \times 10^{-27}\,kg$

$$\Delta m = m_U - (m_{Kr} + m_{Ba} + m_n)$$
$$= 235.043930\,u - (89.919517 + 143.922953 + 1.008665)\,u$$
$$= 0.192795\,u$$
$$= 0.192795 \times 1.66 \times 10^{-27}$$
$$= 3.200397 \times 10^{-28}\,kg\text{, per U atom}$$

$$\Delta E = c^2 \Delta m$$
$$= 9.00 \times 10^{16} \times 3.200397 \times 10^{-28}$$
$$= 2.8803573 \times 10^{-11}\,J\text{, per U atom}$$

Energy released per kg U
$$= 2.8803573 \times 10^{-11} \times 2.56 \times 10^{24}$$
$$= 7.4 \times 10^{13}\,J = 74\,000\,000\,MJ$$

Q10

Use the data below to calculate the energy released by the nuclear fusion of deuterium, hydrogen-2, with tritium, hydrogen-3. **(4 marks)**

$m_n = 1.008665$ u

atomic mass of deuterium = 2.014102 u

atomic mass of tritium = 3.016050 u

atomic mass of He-4 = 4.002602 u

$\Delta m = (2.014102 + 3.016050) - (4.002602 + 1.008665) = 0.018885$ u

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

$= 9.00 \times 10^{16} \times 0.018885 \times 1.66 \times 10^{-27}$

$= 2.82 \times 10^{-12}$ J = 17.6 MeV

Q11

Copy and complete the transformation equations below:

(a) $^{244}_{94}Pu \rightarrow {}^{4}_{2}He +$ ________ **(2 marks)**

$^{244}_{94}Pu \rightarrow {}^{4}_{2}He + {}^{240}_{92}U$

(b) $^{32}_{15}P \rightarrow$ ________ $+ {}^{0}_{-1}e$ **(2 marks)**

$^{32}_{15}P \rightarrow {}^{32}_{16}S + {}^{0}_{-1}e$

Q12

Radon gas has a half-life of about 1 minute.
A sample of radon gas is placed into a sealed container and a detector in the container records an activity of 160 counts per second, after allowing for background radiation.

(a) State what fraction of the original isotope remains after: (i) 1 minute, (ii) 2 minutes, (iii) 5 minutes. **(3 marks)**

(i) 1 minute = 1 half-life so half of the original isotope remains

(ii) 2 minutes = 2 half-lives so $\left(\frac{1}{2}\right)^2 = \frac{1}{4}$

(iii) 5 minutes = 5 half-lives so $\left(\frac{1}{2}\right)^5 = \frac{1}{32}$

(b) Predict the activity after 10 minutes. **(2 marks)**

After 10 half-lives the fraction remaining would be $\left(\frac{1}{2}\right)^{10} \approx 10^{-3}$, so the activity would be about $160 \times 10^{-3} \approx 0$. It is very likely that all of the radon has decayed.

Q13

The graph below shows displacement versus time for a simple harmonic oscillator:

(a) What is the amplitude and the frequency of this oscillator? **(3 marks)**

Amplitude = 4.5 cm. Time period = $\frac{0.080}{2}$ = 0.040 s, so $f = \frac{1}{T} = \frac{1}{0.040} = 25$ Hz

(b) At what times does the oscillator have maximum positive velocity? **(2 marks)**

Maximum positive velocity corresponds to maximum positive gradient, so the times are 0.030 s and 0.070 s.