Topic 5 Further Mechanics   Answers

P Pearson

Topic 5 Further mechanics

5A Further momentum

5A.1 Energy in collisions
1   (a) 8.73×10^{-13} J
        (b) 5.46×10^{6} eV
        (c)   5.46 MeV
2   (a) 3.90 m s^{-1}
        (b) $\Delta E = -6.6$ J
3   6.68×10^{-27} kg, so likely to be an alpha particle

5A.2 More collisions
1   (a)   22 000 Ns
        (b)   3.24 s
2   (a)   The cue ball's velocity is virtually the same as the black, but on a downward 45° trajectory. It is highly likely to enter the bottom corner pocket.
        (b)   Kinetic energy is conserved, so it is an elastic collision.
3    $v_{imp} = 1.1 \times 10^{9}$ m s^{-1}; this is faster than the speed of light.
4   Students' own answers. For example:
    The table top could be marked with a grid of squares (or graph paper) for improved position determination. The size of the ball bearings could be reduced so that their position is more accurately determined, and also so that the trajectories change more on collision, reducing the percentage errors in trajectory direction determination.

5A Exam practice
1   A
2   C
3   B
4   C
5   Any four of the following:
    Considers momentum
    Calculation of momentum of xenon or spacecraft
    Calculation of a second momentum
    OR calculation of speed of spacecraft
    A statement that the prediction is correct
    OR a statement that the increase is (approximately) 8 m s^{-1} (mark awarded only if based on correct calculations)
    (Calculation to find the speed of the xenon or either mass scores max 3 marks)
    Suggested calculation:
    Momentum of xenon = 0.13 kg × 30 000 m s^{-1} = 3900 kg m s^{-1}
    Momentum of spacecraft = 486 kg × 8 m s^{-1} = 3888 kg m s^{-1}
    OR
    Momentum of xenon = 0.13 kg × 30 000 m s^{-1} = 3900 kg m s^{-1}
    Momentum of spacecraft = 486 kg × v
    $v = \dfrac{3900\ kg\ m\ s^{-1}}{486\ kg} = 8.02$ m s^{-1}
6   (a)   Sum of momenta before (collision) = sum of momenta after (collision)
        OR the total momentum before (a collision) = the total momentum after (a collision)
        OR total momentum remains constant
        OR the momentum of a system remains constant
        Providing no external / unbalanced / resultant force acts
        OR in a closed system
        (b)   (i)   Use of equation(s) of motion sufficient to get answer

Initial speed = 1.1 (m s^{-1})
Suggested calculation:
$$s = \frac{(u+v)t}{2}$$
$$0.69 \text{ m} = \frac{(u+0) \times 1.3 \, s}{2}$$
$u = 1.06$ m s^{-1}

(ii)   Constant acceleration / deceleration

(iii)   Use of momentum = mv
Calculation of momentum after collision using correct mass
Speed of pellet = 117 or 124 or 129 (m s^{-1})
Suggested calculation:
Momentum after = (97.31 + 0.84) g × 1.06 m s^{-1} = 104 g m s^{-1}
Momentum before = momentum after
Speed of pellet = $\frac{104 \, g \, m \, s^{-1}}{0.84 \, g}$ = 124 m s^{-1}

(c)   (i)   QWC (quality of written communication) – work must be clear and organised in a logical manner using technical wording where appropriate; including:
Mention of momentum
Pellet (bounces back so) has negative momentum / velocity
OR momentum after = momentum of car − momentum of pellet
Pellet undergoes a bigger momentum / velocity change
OR mass of car is less

(ii)   Reference to greater horizontal momentum / force

(d) $E_k \rightarrow E_{grav}$ of pendulum is correct OR KE after collision is correct
E_k in collision not conserved OR not an elastic collision OR inelastic collision (no marks for just 'KE is lost')
Some energy becomes heat
E_k (of pellet before collision) is greater than 0.16 J

7   (a)   Conversion of MeV to J
Use of $E_k = \frac{1}{2} mv^2$
Max velocity = 4.1 × 10^6 (m s^{-1})
Suggested calculation:
$$v = \sqrt{\frac{2 \times 1.2 \, Mev \times 1.6 \times 10^{-13} \, J}{14 \times 1.66 \times 10^{-27} kg}}$$

velocity = 4.06 × 10^6 m s^{-1}

(b)   (i)   Correct momentum of any particle, e.g. Nux (must contain u)
Correct equation from conservation of momentum
Rearrange for z
Suggested calculation:
Nux = 14uy + Nuz
Nz = Nx − 14y

(ii)   Kinetic energy is conserved

(iii)   ½ Nux^2 OR ½ Nuz^2 OR ½ 14uy^2
E_k nitrogen atom = E_k neutron before − E_k neutron after
OR E_k nitrogen atom = E_k lost by neutron

(c)   (i)   Use of equation; N in the denominator must be included, given with y = 3.0 × 10^7
OR y = 4.1 × 10^6
In equation given use of:
N + 1 with y = 3.0 × 10^7
OR
N + 14 with y = 4.1 × 10^6
In equation given use of:
N + 1 with y = 3.0 × 10^7
AND
N + 14 with y = 4.1 × 10^6

Suggested calculation:
For hydrogen: $2Nx = 3.0 \times 10^7 (N + 1)$
For nitrogen: $2Nx = 4.1 \times 10^6 (N + 14)$
Equating gives: $4.1 \times 10^6 (N + 14) = 3.0 \times 10^7 (N + 1)$
(so $N = 1.06$)

(ii)   Collision might not be elastic
OR speed (of particles) approaches speed of light (so mass increases)

Topic 5 Further Mechanics   Answers

5B Circular motion

5B.1 Circular motion basics
1   (a)   720°
       (b) 0.2π rad (= 0.63 rad = $\frac{\pi}{5}$ rad)
2   18.8 rad s^{-1}
3   (a)   (i)   3.5 rad s^{-1}
               (ii)   4.7 rad s^{-1}
               (iii)   8.2 rad s^{-1}
       (b)   3.6 m s^{-2}
4   (a) 7.27×10^{-5} rad s^{-1}
       (b)   465 m s^{-1}
       (c)   0.034 m s^{-2}
5   1.86%

5B.2 Centripetal force
1   2530 N ($\omega = 1.4$ rad s^{-1})
2   (a)   2.54 N
       (b) $W = 736$ N, so centripetal force is much smaller
       (c)   Centripetal force is provided by weight, so reaction is less than weight by the amount of the centripetal force (in order that there is a resultant to provide centripetal acceleration). At South Pole, zero centripetal force, so reaction is 2.54 N larger than at equator.

5B Exam practice
1   C
2   B
3   B
4   C
5   (a)   Use of $F = \frac{mv}{t}$ or $F = ma$
               Answer = 2.0×10^{5} N
               E.g. $F = \frac{12\,000 \times 57}{3.5}$
       (b)   Arrow down labelled mg / W
               Arrow up labelled, e.g. R / reaction / force from seat
               Equal length vertical arrows from a clear single point / centre of mass and 'bottom'
       (c) $4mg - mg$ OR $3mg$
                $\frac{(m)v^2}{r}$
               Answer = 110 (m)
               E.g. $3mg = \frac{mv^2}{r}$
               $r = \frac{(57)^2}{3g}$
       (d)   Use of KE/PE conservation
               Answer = 23 (m s^{-1})
               E.g. ½ $m(57)^2$ = ½ $mv^2 + mg \times 139$
               v^2 = ½ $(57)^2 - 9.81 \times 139$
       (e)   Using $(m)g$ only
               Answer $r = 54$ m
               E.g. $mg = \frac{mv^2}{r}$
               $r = \frac{(23)^2}{9.81}$
6   (a)   Conversion from per minute to per second
               Conversion from revolutions to radians

Suggested calculation:

20 revolutions = $20 \times \frac{2\pi}{60}$ (= 2.1 rad s^{-1})

(b)   Use of $r\omega^2$

Answer in range 6–13 m

26–57 m s^{-2} (correctly corresponding to radius estimate)

7   (a)   Use of $v = \frac{2\pi r}{t}$ OR $v = r\omega$ AND $T = \frac{2\pi}{\omega}$

$t = 1.5 \times 10^3$ s (24.6 minutes)

Suggested calculation:

$t = \frac{2\pi r}{v}$

$t = \frac{2\pi \times 61\ m}{0.26\ m\ s^{-1}}$

$t = 1473$ s

(b)   Use of $F = \frac{mv^2}{r}$

$F = 11$ N

Suggested calculation:

$F = \frac{9.7 \times 10^3\ kg \times (0.26\ m\ s^{-1})^2}{61\ m}$

$F = 10.7$ N

(c)   (i)   Three arrows all pointing to the centre of the circle

(ii)   QWC (quality of written communication) – work must be clear and organised in a logical manner   using technical wording where appropriate; including:

Maximum at C / bottom AND minimum at A / top

At C, contact / reaction force (R) greater than weight

($R - W = \frac{mv2}{r}$ OR $R = W + \frac{mv2}{r}$)

At A, contact / reaction force is less than the weight

($W - R = \frac{mv2}{r}$ OR $R = W - \frac{mv2}{r}$)

Statement that centripetal force / acceleration is provided by weight / reaction

OR centripetal force is the resultant force

(This is a QWC question so a statement of the equations can score the marks but to get full marks there must be clear explanation in words.)

8   This is as per the experiment on page 21:

Description of apparatus and activity

Measure time for ten revolutions and divide by ten

to find time period

Repeat for various different hanging masses which will give $F = mg$

Control variables: radius of revolution (confirmed with marker on string), mass of rotating mass

Plot a graph of F (y-axis) against v^2 (x-axis) will verify the equation if it shows direct proportionality

Topic 6 Electric and magnetic fields

6A Electric fields

6A.1 Electric fields

1   4.8×10^{-17} N
2   8000 N C^{-1}
3   4.8×10^{11} m s^{-2}
4   (a) $100\,000$ V m^{-1}
     (b) 3.2×10^7 m s^{-1}
     (c)   Parallel plates with field lines with arrows from $+$ to $-$ / ground; parallel equipotentials; labelling of potential difference across field, similar to fig C
     (d)   Proton has same magnitude charge as electron but is more massive; reduced acceleration; charge is of opposite sign, so acceleration is in opposite direction
5   (a)   Negative
     (b)   Equal sized vertical arrows up and down from the drop, labelled 'weight' or 'mg' (down) and 'electrostatic' or 'coulomb force' (up)
     (c) $E = 2 \times 10^5$ V m^{-1} (OR N C^{-1})
     (d) $mg = EQ$
   Charge $= 4.8 \times 10^{-19}$ C
     (e)   3

6A.2 Radial electric fields

1   (a)   Radial field emanating from circle representing dome (drawn as non-point source); field lines from surface of dome drawn so they would come from centre of circle; arrows on field lines away from sphere; no field inside dome, similar to fig A
     (b)   Equipotentials concentric with dome surface; increasing separation of equipotentials; surface voltage is 15 000 V, so equipotential labelling should decrease from that following $\frac{1}{r}$ relationship
     (c) $56\,000$ V m^{-1}
     (d) 4500 V
2   It would feel no force as the electric field at the exact centre is zero; indicated on the diagram by the absence (or equidistance) of field lines.
3   Diagram as per fig B(b) but with the point charges labelled as negative; field line arrows pointing to electrons (i.e. opposite direction to fig B(b))
4   The charges are forced closest together on the spike, and hence they generate the strongest field at the point; indicated on the diagram by the closeness of the equipotential lines.
5   (a) 5.1×10^{11} V m^{-1}
     (b) $F = EQ = 8.2 \times 10^{-8}$ N

6A.3 Coulomb's law

1   2.12×10^{-6} N
2   (a) 1.14×10^{17} V m^{-1}
     (b) 0.036 N
3   Separation must be measured to the centres of the spheres, which is difficult with spherical objects and may introduce uncertainties.
4   Students' own estimates. With body surface area of 2 m $\times$ 0.5 m, and weight 800 N: $r = 1.0 \times 10^{-5}$ m

5   Graph of $\frac{1}{r2}$ against d gives a reasonable straight best-fit line that passes through the origin, proving proportionality, and verifying Coulomb's law, as F is proportional to d in this experiment.
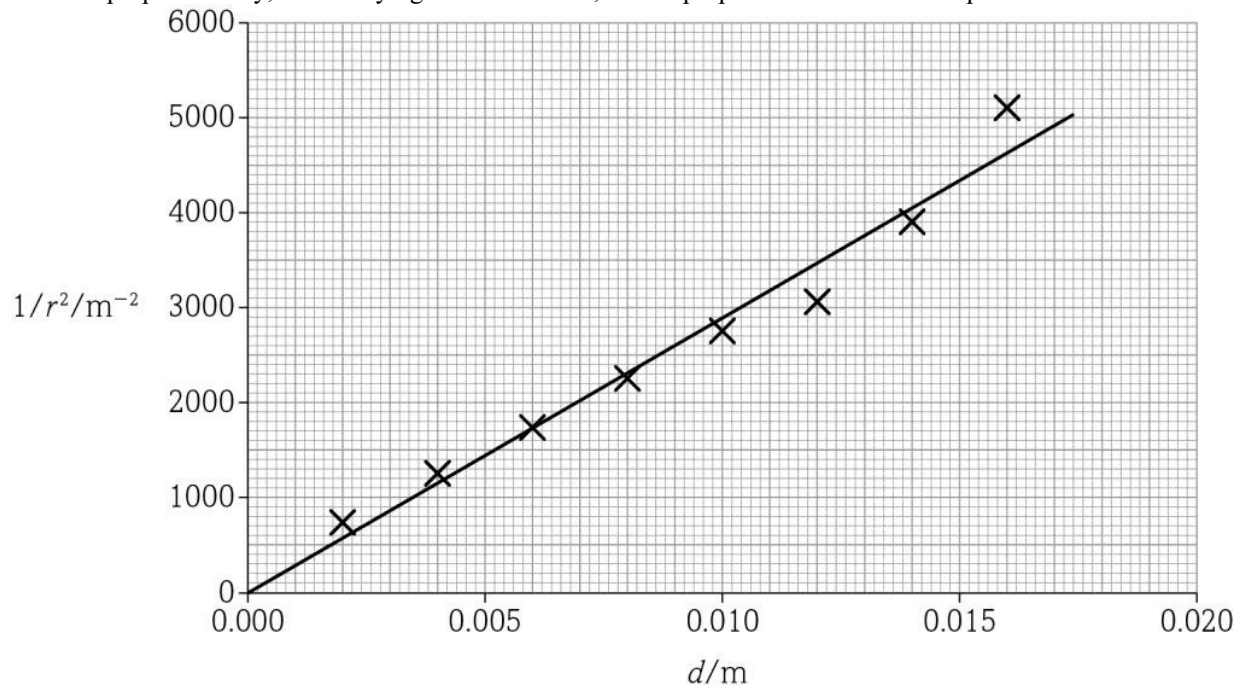
6A Exam practice

1   B
2   B
3   B
4   C
5   D
6   (a)   Space / area / region where a force acts on a charged particle
           The force is the same at all points
           OR field strength is constant
           OR field lines equispaced
           (A diagram with a minimum of three equispaced parallel lines, with arrows for 2nd mark is acceptable.)
       (b)   Two *parallel* plates
           Connected to a potential difference OR potential difference is applied
           Practical method to show force
           E.g. seeds in tray of glycerol
           Charged foil on end of rule
           Charged pith ball on thread
           Beam of electrons (in teltron tube)
           Charged oil drops
           (All 3 marks can be scored from a diagram. To score the 3rd mark the set-up must be labelled.)
7   (a)   Weight / W / mg vertically down
           Tension / T parallel to thread and pointing away
           Electrical (force) horizontal to left
           (The lines must start on the ball and have arrow heads to indicate direction.)
       (b)   (i)   Use of $T \cos 35° = mg$ OR $T \sin 55° = mg$
                  Convert g to kg and $\times$ 9.81
                  Tension $= 3.2 \times 10^{-2}$ (N)
                  Suggested calculation:
                  $T \cos 35° = mg$
$$T = \frac{2.7 \times 10^{-3}\,kg \times 9.81\,N\,kg^{-1}}{\cos 35°}$$
                  $T = 0.0323$ N
           (ii)   Equate electric force to $T \sin 35°$ OR $T \cos 55°$ OR $W \tan 35°$
                  OR use of Pythagoras' theorem
                  $F_E = 0.018$ OR 0.019 (N)
                  Suggested calculation:
                  $F_E = 0.032 \times \sin 35°$
                  $F_E = 0.018$ N
           (iii)   Use of $F = \frac{Q^2}{4\pi\varepsilon_0 r^2}$ OR $F = \frac{kQ^2}{r^2}$
                  Convert cm to m
                  $Q = (2.9 - 3.1) \times 10^{-7}$ C
                  Suggested calculation:
$$Q^2 = \frac{Fr^2}{k}$$
$$Q^2 = \frac{(0.020\,N) \times (20.6 \times 10^{-2}\,m)^2}{8.99 \times 10^9\,N\,m^2\,C^{-2}}$$
                  $Q = 3.07 \times 10^{-7}$ C
       (c)   Both balls would move through the same angle/distance
           OR the balls are suspended at equal angles (to the vertical)
           (Because) the force on both balls is the same
8   (a)   Use of $E = \frac{V}{d}$
           Answer $= 1.5 \times 10^5$ V m^{-1} or N C^{-1}
           E.g. $E = \frac{1.5}{10 \times 10^{-6}}$

       (b)   Opposite forces (act on either end of molecule)

              Molecule rotates / aligns with field
at top / + at bottom

9   (a) $Q = 4\pi\varepsilon_0 rV = 4 \times 3.14 \times 8.85 \times 10^{-12} \times 0.1 \times 1200$
                  $= 1.33 \times 10^{-8}$ C

     (b)   (i) $V = \dfrac{Q}{4\pi\varepsilon_0 r}$

                    $= \dfrac{1.33 \times 10^{-8}}{4 \times 3.14 \times 8.85 \times 10^{-12} \times 0.45}$
                    $= 267$ V

         (ii) $V = \dfrac{Q}{4\pi\varepsilon_0 r}$

                    $= \dfrac{1.33 \times 10^{-8}}{4 \times 3.14 \times 8.85 \times 10^{-12} \times 0.55}$
                    $= 218$ V

     (c) $\frac{1}{2} m_e v^2 = q\Delta V$
             $\Delta V = 48.5$ V
             $v = \sqrt{\dfrac{2q\Delta V}{m_e}}$
             $v = \sqrt{\dfrac{2 \times 1.6 \times 10^{-19} \times 48.5}{9.1 \times 10^{-31}}}$
             $v = 4.1 \times 10^6$ m s^{-1}

10   (a)   At least three vertical lines spread over symmetrically over more than half of the plate length and touching both plates
            All lines equispaced and parallel (gaping to avoid oil drop is not allowed)
            Arrow pointing downwards

     (b)   Negative / − / −ve
            (Negative and/or positive does not get the mark)

     (c)   Upward force labelled: electric (force) OR electrostatic (force)
            OR force due to electric field OR electromagnetic (force)
            Downward force labelled: mg, weight, W, gravitational force
            (For both marks, the lines must touch the drop and be pointing away from it.)

     (d)   (i) $E = \dfrac{5100\ \text{V}}{2\ \text{cm}}$
                  Convert cm to m
                  Use of $QE = mg$ (1.18×10^{-13} kg)
                  $Q = 4.6 \times 10^{-19}$ C
                  Suggested calculation:
                  $E = \dfrac{V}{d}$
                  $F = EQ = mg$
                  $Q = \dfrac{mg}{E} = \dfrac{mgd}{V}$
                  $Q = \dfrac{1.20 \times 10^{-14}\ \text{kg} \times 9.81\ \text{m s}^{-2} \times 0.02\ \text{m}}{5100\ \text{V}}$
                  $Q = 4.62 \times 10^{-19}$ C

         (ii)   Answer to (d)(i) divided by e
                  3 electrons OR sensible integer number less than 500
                  Suggested calculation:
                  number of electrons $= \dfrac{4.62 \times 10^{-19}\ \text{C}}{1.6 \times 10^{-19}\ \text{C}}$
                  number $= 2.9$, i.e. 3 electrons

11   Any five from:
       Radial field around electron
       Field line arrows pointing towards electron
       Potential lines are perpendicular to field lines
       Potential lines drawn as concentric circles (or spheres) around electron
       Distance of potential lines increases as $\dfrac{1}{r}$
       Explanation that potential follows equation: $V = \dfrac{Q}{4\pi\varepsilon_0 r}$
       Diagram illustrating any of the above points

6B Capacitors

6B.1 Capacitor basics

1   0.02 F
2   (a)   0.08 C
     (b)   The charge will spread onto the other capacitor until they each have half of the original charge (0.04 C). This will result in a p.d. of 4 V across each capacitor (and/or across the parallel combination).
3   0.0036 J
4    $E = 0.0486$ J; so lights bulb for 4.86 ms

6B.2 Charging and discharging capacitors

1   30 s
2   Current: Initially, the electric field from the supply sends a large surge of electrons onto the capacitor, so the current starts at its maximum. After a little time, the electrons already stored on the capacitor reduce the effective push (or electric field) from the supply, so the charge movement is reduced – a smaller current. Eventually, the capacitor has as much charge as the 6 V supply can push onto it, and the mutual repulsion of electrons already stored stops any further charge moving onto the capacitor; the current falls to zero.
     p.d.: Initially, the capacitor has no charge on it, so its p.d. is zero. After a little time, the charge stored across the capacitor creates some p.d., which could be measured using a voltmeter. Eventually, the capacitor has as much charge as the 6 V supply can push onto it, which will be when it has also reached a voltage of 6 V, and it will remain at this value.
     Charge: Initially, the capacitor has no charge on it. The current starts at its maximum so, after a little time, some charge is stored on the capacitor. The reduced current continues to add charge to the capacitor but at a slower rate. Eventually, when the current reaches zero, no more charge is added to the capacitor, and the amount on it remains constant at its maximum, CV.
3   Basic exponential decay curve as per fig B(a): initial current is 0.6 mA. This should fall to 0.22 mA in 0.5 s. At 1 s, the current has dropped to 0.08 mA, then at 1.5 s it is 0.03 mA, finishing at 0.01 mA by 2 s. Depending on scale, it is likely that the final half second should look horizontal along zero mA.

6B.3 Capacitor mathematics

1   (a)   0.006 A
     (b)   Approximately 8 s
     (c)   Need $RC = 74$, so e.g. increase R to 740 Ω
2   0.041 A
3    $\ln V = \ln V_0 - \dfrac{t}{RC}$

     In the experiment, take readings of p.d. against time. By plotting $\ln V$ against t, the log equation shows we will get a straight-line graph. The gradient will be $-\dfrac{1}{RC}$, so if R is known, this will give us C. Just plotting V against t would give the exponential curve, which is difficult to analyse accurately.

6B Exam practice

1   C
2   D
3   C
4   D
5   (a)   (i)   Capacitor charges up OR p.d. across capacitor becomes (equal to) p.d. of cell
                   Negative charge on one plate and positive charge on the other
                   OR opposite charges on each plate
                   OR movement of electrons from one plate and to the other (around the circuit)
            (ii)   As capacitor charges current decreases
                   OR as capacitor charges current drops to zero
                   OR p.d. across capacitor becomes (equal to) p.d. of cell
                   No current through R (means no p.d.)
                   OR $V_{\text{cell}} = V_{\text{capacitor}} + V_{\text{resistor}}$

(b)   QWC (quality of written communication) – work must be clear and organised in a logical manner using technical wording where appropriate; including:

$Q = CV$

As C increased then charge flowed (OR more charge stored) on capacitor

So p.d. across R

Charge flow / current /output signal reversed when plates move apart

OR

$Q = CV$

As C increased p.d. across capacitor decreased

So p.d. across R must increase

p.d. reverses when plates move apart

(c)   Use of time constant = RC OR attempt to find half-life

Time constant = 0.005 (s) OR $t_{½}$ = 0.0035 (s)

Use of $T = \frac{1}{f}$ (to give T = 0.05 s for the lowest audible frequency)

Capacitor completes discharging/charging during cycle of signal

(Last mark can only be gained if supported by calculations.)

Suggested calculation:

$RC = 10 \times 10^6 \, \Omega \times 500 \times 10^{-12}$ F

$RC = 0.005$ s

$f = \frac{1}{T} = \frac{1}{20} = 0.05$ s

6   (a)   Use of $Q = CV$ with V = 16 V

Max value of C = 12 000 (μF)

μF means 10^{-6} conversion of μF to F

Suggested calculation:

$C_{max} = 1.20 \times 10\,000 = 12\,000$ F

$C_{max} = 12\,000$ F $\times$ 16 V

$Q_{max} = 0.192$ C

(b)   Use of $\frac{1}{2}QV$ OR $\frac{1}{2}CV^2$

Energy = 1.5 J

Suggested calculation:

$W = \frac{1}{2} \, 0.192$ C $\times$ 16 V

Energy = 1.54 J

7   (a)   (i)   Answer = 22 s

Suggested calculation:

$T = 220 \times 10^3 \, \Omega \times 100 \times 10^{-6}$ F

(ii)   Time taken for the p.d. / charge / current to change by 63% OR to fall to $\frac{1}{e}$ of its original value OR to fall to $(\frac{12}{e})$ V

OR to fall to 4.41 V

(b)   (i)   To reduce / prevent charge / current through the voltmeter

(ii)   Precision of stopwatch much less than reaction time

OR uncertainty significantly less than 22 s

(iii)   Repeat experiment and calculate mean value

OR use graphical method

(c)   Correct expansion $\ln V = -\frac{t}{RC} + \ln V_0$

Compare with $y = mx + c$

OR state that RC is constant

(d)   ln values correct and to at least 2 sf

Axes labelled with quantity and unit; y-axis must be labelled ln (V/V)

Scales (expect 1 cm : 0.1 vertically)

Points correctly plotted and best-fit straight line

(e)   (i)   Large triangle (at least half the drawn line) with correct values

Correct calculation for T in range $19.8 < T < 20.2$ and at least 3 sf

(ii)   Use 22 s and graph value to calculate % difference correctly

Suggested calculation:

$$\frac{20.0 - 22.0}{22} = \frac{2.0}{22} = 9.1\%$$

(f)   (i)   ln 5 (= 1.609) used to find time from graph

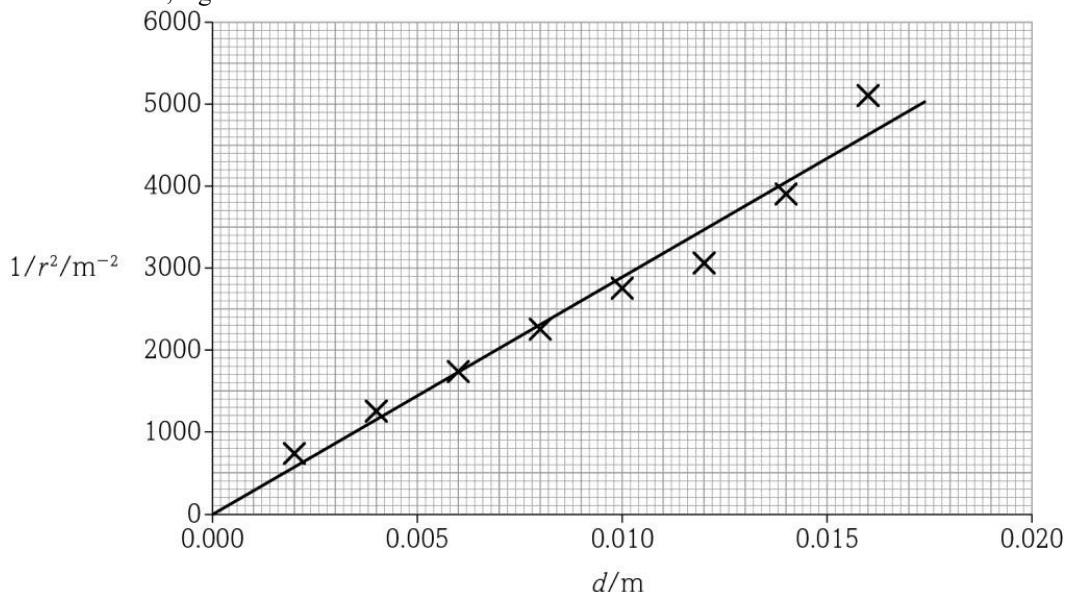Value in range 17.4–17.6 s and to 3 sf

(ii)   Answer = 150 kΩ (option C)

Suggested calculation:

$$220 \times \frac{12}{17.5} = 150$$

6C Electromagnetic effects

6C.1 Magnetic fields

1 (a) Sketch should include labels for geographic North and South Poles and field lines as per bar magnet, with arrows pointing along field lines from geographic South Pole to geographic North, e.g.

(b) The poles of a bar magnet have the field lines closest together, so the North and South Pole of the Earth would be where B is greatest.

2 (a) Estimate area of body perpendicular to field lines as 2 m × 0.5 m, gives $\Phi = 5 \times 10^{-5}$ Wb

(b) $\Phi = 6.8 \times 10^{-11}$ Wb

3 0.0261 Wb-turns

6C.2 Electric motors

1 Fleming's left hand rule connects directions of magnetic field, electric current and force when determining effect on current-carrying conductor in a magnetic field. Thumb = force; first finger = magnetic field; second finger = conventional current.

2 (a) Down

(b) Away from reader

(c) No force

3 With electromagnets, the magnetic field can be varied easily, but the magnetic field is zero when the electric current is switched off.

6C.3 Magnetic forces

1 (a) 4.8×10^{-6} N

(b) 4.0×10^{-21} N

(c) 3.2×10^{10} m s^{-1}; faster than the speed of light

2 1.22×10^{-13} N

3 $v = \frac{l}{t}$ and $I = \frac{Q}{t}$, therefore $F = BIl = B\frac{Q}{t}l = B\frac{l}{t}Q = BvQ$, where Q is a collection of charge

4 ^{23}Na$^+$ $r = 0.0127$ m; ^{22}Na$^+$ $r = 0.0124$ m. 0.3 mm is an easily detectable change. When the settings for B and V mean the radius of travel does not match exactly with the shape of the machine, the ions do not reach the detector at all, and the detectable differences are orders of magnitude less than the difference here.

6C.4 Generating electricity

1 (a) 1.65×10^{-3} Wb-turns

(b) 0.14 V

2   (a)   The induced e.m.f. rises to a maximum of approximately 250 mV as the magnet enters the coil and reaches full flux linkage. As the magnet continues to fall, the magnetic field starts to leave the coil, so the induced e.m.f. is in the opposite direction, with a peak at approximately 400 mV – higher than previously as gravity is constantly increasing the magnet's speed and hence its rate of change of flux linkage.

    (b)   The induced e.m.f. would drive a current through the bulb first in one direction and then in the opposite direction. If this resulted in a high enough current for it to be a bright enough light to observe, it would look like a brief flash lasting perhaps 0.2 s, followed by a brighter flash of slightly shorter duration.

6C Exam practice

1   C

2   D

3   B

4   Use of $W = mg$
        Use of $F = BIL$
        B = 0.04 T

5   (a)   (Magnetic) flux linkage

    (b)   Lenz's law / conservation of energy
                Induced current / e.m.f. (direction)
                Opposes the *change* (that produced it)

6   (a)   Reference to magnetic flux (linkage)
                Magnet vibrates / moves
                Flux / field through the coil changes
                Induces e.m.f. / p.d.

    (b)   (i)   Use of $T = \frac{2\pi}{\omega}$ for a revolution
                        ω = 3.5 rad s^{-1}
                        Suggested calculation:
                        $\omega = 33 \times \frac{2\pi\ rad}{60\ s}$
                        ω = 3.5 rad s^{-1}

            (ii) ω / T / f remains constant
                        $v = r\omega$ OR $C = 2\pi r$
                        So as the stylus moves towards the centre
                        (tangential/linear) speed/velocity OR path length (per rotation) gets less

7   (a)   QWC (quality of written communication) – work must be clear and organised in a logical manner using technical wording where appropriate.
                Any six from:
                Reference to changing / cutting of field / flux
                Induced e.m.f. proportional to rate of change / cutting of flux (linkage)
                Initial increase in e.m.f. as the magnet gets closer to the coil
                Identify region of negative gradient with magnet going through the coil
                Indication that magnet's speed increases as it falls
                Negative (max) value > positive (max) value
                Time for second pulse shorter
                The areas of the two parts of the graph will be the same (since $N\Phi$ constant)

(b)   Two sequential pulses
             Pulses same height (± 3 mm squares) and width
             Pulses in opposite directions
             Region of zero e.m.f. in the middle
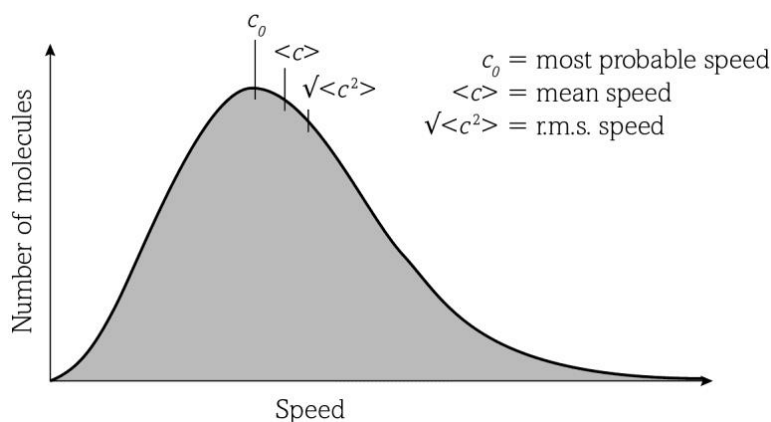   *Example* (peaks could be in opposite directions)
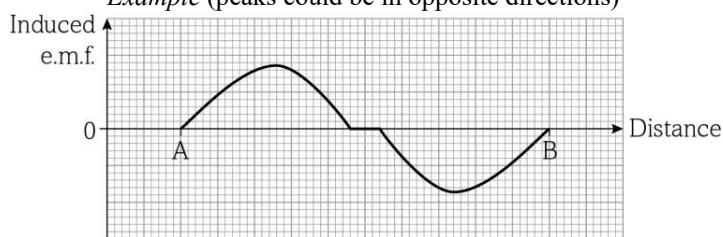
8   (a)   A region where a force is exerted
             On a moving charge OR on a current-carrying conductor
     (b)   (i)   Negative / −q / −ve
             (ii)   The path is circular
                      Because the force (is always) at right angles to the direction of motion of the particle
             (iii)   Use of $F = Bqv(sin\theta)$

                      Using $F = \dfrac{mv^2}{r}$ and equating it to the above expression for force

                      leading to the derivation of $r = \dfrac{mv}{Bq}$

Topic 7 Nuclear and particle physics

7A Probing matter

7A.1 A nuclear atom
1   Students' own answers
2   Main reason is the small size of atoms, experimentation needed to get to smaller and smaller scales, requiring detection technology at smaller and smaller scales
3   Strengths: e.g. distance between nucleus and orbits is much larger than size of particles themselves, as with real Solar System; there is a force holding orbiting objects in place in both cases
       Weaknesses: e.g. electrons do not all orbit in same plane, cf. the ecliptic; planets can have continuously variable orbital energies, electrons have only fixed energy orbits; electrons may not follow continuous path around their orbit, but follow probability function as to their location
4   A = 9; B = 4

Graph: Number of molecules (vertical axis) vs Speed (horizontal axis), showing a Maxwell–Boltzmann type distribution with markers:
- c_0 = most probable speed
- $\langle c \rangle$ = mean speed
- $\sqrt{\langle c^2 \rangle}$ = r.m.s. speed

7A.2 Electrons from atoms
1   (a) 1.2×10^{-10} m
       (b) 3.5×10^{-11} m
       (c) 1.3×10^{-13} m
       (d)   Students' own answers of the order of 10^{-36} m
2   The Davisson–Germer experiment proved diffraction of electrons and measured their effective wavelength.
3   1.45×10^{11} m s^{-1}, which is faster than light
4   Diagram with horizontal and vertical pairs of electric plates. Explanation that horizontal field will be used as time-base and vertical field connected to measuring electrodes in order to alter vertical position of trace.

7A Exam practice
1   (a)   B
       (b)   B
2   C
3   D
4   QWC (quality of written communication) (i and iii) – spelling of technical terms must be correct and the answer must be organised in a logical sequence; including:
       Observations:
       Most alpha particles went straight through
       Some deflected
       (Very) few came straight back / large angle
       Conclusions:
       Atom mainly (empty) space
       Nucleus contains most of the mass
       (Nucleus) very small / tiny
       (Nucleus) charged / positive

5   (a)   Identifying the equations

$E_k = \frac{p^2}{2m}$ and $\lambda = \frac{h}{p}$

OR

$\lambda = \frac{h}{p}$, $p = mv$ and $E_k = \frac{1}{2}mv^2$

Example of derivation

$p = 2mE_k$

$\lambda = \frac{h}{\sqrt{2mE_k}}$

    (b)   Correct substitution of h^2 and m

Use of $E_k = eV$

$\lambda = 2.5 \times 10^{-11}$ m

OR

Use of $E_k = \frac{1}{2}mv^2$ (to find $v = 3.0 \times 10^7$ (m s^{-1}))

Use of $\lambda = \frac{h}{p}$ with correct substitution for h and m

$\lambda = 2.5 \times 10^{-11}$ m

Suggested calculation:

$\lambda = \sqrt{\dfrac{(6.63 \times 10^{-34}\,\text{J s})^2}{2(9.11 \times 10^{-31}\,\text{kg})(2500\,\text{V})(1.6 \times 10^{-19}\,\text{C})}}$

$\lambda = 2.46 \times 10^{-11}$ m

OR

$v = \sqrt{\dfrac{2(2500\,\text{V})(1.6 \times 10^{-19}\,\text{C})}{9.1 \times 10^{-31}\,\text{kg}}} = 3.0 \times 10^7$

$\lambda = \dfrac{6.63 \times 10^{-34}\,\text{J s}}{(9.1 \times 10^{-31}\,\text{kg})(3.0 \times 10^7\,\text{m s}^{-1})}$

6   (a)   (i)   Straight through, zero deflection, direction fired in

            (ii)   (Atom consists) mainly/mostly of *empty space*

                      OR volume of atom very much greater than volume of nucleus

    (b)   Most of the mass is in the nucleus/centre

          (It is not enough to say that the nucleus is dense/concentrated. Looking for idea that nearly all of the atom's mass is in the nucleus.)

          Nucleus/centre is *charged* (just saying the nucleus is positive does not get the mark)

    (c)   (i)   Electrostatic / electromagnetic / electric / coulomb

            (ii)   Arrow starting on the path at closest point to the nucleus

                   Arrow pointing radially away from nucleus

            (iii)   Deflection starts earlier

                   Final deflection is greater

                   (Paths should diverge.)

7   Small central nucleus

Most of atom is empty space

Nucleus contains all positive charge in an atom

Nucleus contains most of atom's mass

Most alpha particles pass straight through with no deflection

Some alpha particles pass through the nucleus and are deflected sideways

A very few alpha particles are deflected by more than 90°

Diagram illustrating any of the above points

8   (a)   For good diffraction to occur, the size of the gap should be approximately the same size as the wavelength

          The interatomic spacing in rubber is approximately 0.11 nm

    (b)   (i) $\lambda = \frac{h}{p}$

            (ii) $p = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34}}{0.11 \times 10^{-9}}$

                  $p = 6.03 \times 10^{-24}$ kg m s^{-1}

            (iii) $v = \frac{p}{m} = \frac{6.03 \times 10^{-24}}{9.11 \times 10^{-31}}$

                  $= 6.62 \times 10^6$ m s^{-1}

            (iv) $V = \frac{\frac{1}{2}mv^2}{e} = \frac{0.5 \times 9.11 \times 10^{-31} \times (6.62 \times 10^6)^2}{1.6 \times 10^{-19}}$

Answers

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$V = 125$ V

(c)   Neutrons have a much larger mass than electrons

So for the same de Broglie wavelength/momentum, they could move much slower

Approximately 2000 times slower / 3300 m s^{-1}

9   (a)   (i)   Use of $\lambda = \dfrac{h}{p}$ and $p = mv$ OR $v = \dfrac{h}{m\lambda}$

Use of $m = 9.11 \times 10^{-31}$ kg

$v = 7.28 \times 10^6$ m s^{-1}

Suggested calculation:

$\lambda = \dfrac{h}{mv}$

$v = \dfrac{6.63 \times 10^{-34} \text{ J s}}{9.11 \times 10^{-31} \text{ kg} \times 1.0 \times 10^{-10} \text{ m}}$

$v = 7.28 \times 10^6$ m s^{-1}

(ii)   Use of $E_k = \frac{1}{2}mv^2$ OR $E_k = \dfrac{p^2}{2m}$ OR $E_k = 2.41 \times 10^{-17}$ J

Divided by 1.60×10^{-19}

$E_k = 151$ eV

Suggested calculation:

$E_k = \dfrac{\frac{1}{2}(9.11 \times 10^{-31} \text{ kg})(7.28 \times 10^6 \text{ m s}^{-1})^2}{1.60 \times 1^{-19} \text{ J eV}^{-1}}$

$E_k = 151$ eV

(b)   The wavelength is similar in size to the nucleus

The wavelength/nucleus is (much) smaller / 10^{-15}m / 10^{-14} m

7B Particle accelerators and detectors

7B.1 Particle accelerators
1. The particles are getting faster; the p.d. switches at a fixed frequency; to ensure p.d. switch at mid tube every time, tubes must get progressively longer
2.
   (a) 1.4×10^7 m s^{-1}
   (b) 2.3×10^{-20} kg m s^{-1}
   (c) 0.58 T
   (d) 8.8 MHz
3.
   (a) 2.97×10^8 m s^{-1}
   (b) 7.4×10^{-11} J
   (c) 7.4×10^{-11} J $= 4.6 \times 10^8$ eV which is several orders of magnitude smaller than 7 TeV
   (d) The high-speed protons have a significantly greater mass than 1.67×10^{-27} kg because of the relativistic increase in mass at speeds near the speed of light.

7B.2 Particle detectors
1. The ions created can be detected electrically; and causing ionisation is a common property of fast-moving ion particles.
2. Red = electron
3. Radius of curvature of track is smaller above lead bar, so particle slower above, so must have travelled upwards through lead

7B.3 The Large Hadron Collider
1. $r = \dfrac{mv}{Bq}$ so if we know the magnetic field strength and the speed of particle   movement, we can find the charge mass ratio for this particle
2. If a particle track changes direction suddenly, that is a breach of conservation of momentum. This can only be reconciled if a particle not creating tracks is involved in a collision with the particle.
3. The collisions produce a huge variety of other particles, and so a large range of detectors is necessary. Each experiment concentrates on detectors of particular types. Also, it will not be possible for another lab elsewhere to verify the results, as building the LHC is such a monumental undertaking. Thus it must reproduce its own results, and the four separate experiments can independently verify each other.
4. Students' own answers

7B Exam practice
1. B
2. A
3. D
4.
   (a) (Magnetic) force acts at right angles to ion motion/current
   Force is the centripetal force OR causing centripetal acceleration OR direction of acceleration/force is to centre (of circle)
   (b) $F = Bqv$ OR $r = \dfrac{p}{Bq}$

   $F = \dfrac{mv^2}{r}$ OR $p = mv$

   $f = \dfrac{v}{2\pi r}$ OR $f = \dfrac{\omega}{2\pi}$ OR $T = \dfrac{2\pi r}{v}$ OR $T = \dfrac{2\pi}{\omega}$
   (c)
   (i) Positive (field) above AND below (the ion)
   Which repels the ion
   (ii) $\dfrac{3 \times 32.0645}{10 \times 10^6}$
   $= 0.000\ 0096$(u)
   (iii) Convert MeV to u using 931.5 conversion
   Mass loss $= 0.0024$(u) (and this is more than $0.000\ 01$u)
   Suggested calculation:
   mass loss $= \dfrac{2.2\ \text{MeV}}{931.5} = $ u
5.
   (a) Force on (charged) particles at right angles to motion

Causes circular motion (not spiral / curved)

OR force/acceleration is centripetal

(b) (i) Momentum: $p = mv$ OR $r = \frac{mv}{Be}$

$v = \frac{2\pi r}{T}$ OR $v = r\omega$ OR $\omega = \frac{Be}{m}$

Use of $f = \frac{1}{T}$ OR $\frac{\omega}{2\pi}$

Suggested calculation:

$Ber = mv$

$Ber = \frac{m2\pi r}{T}$

$Be = m2\pi f$

(ii) (Protons) accelerated / given energy, in the gaps / between dees / from one dee to the other

Every half rotation/semicircle later (polarity of dees) needs a change

(iii) Relativistic effect / v approaching c / mass increases

So frequency decreases

(c) Must be accelerating due to circular motion

(Speed constant but) direction/velocity changing

6   Charged particles can be accelerated by electric fields

Both accelerators use fixed frequency alternating p.d.

Linac acceleration tubes of increasing length

Because particles move faster further along the accelerator

Moving charged particles can be deflected in a circular path by a perpendicular magnetic field

Cyclotron uses circular D-shaped electrodes

Particles accelerate across gap between dees

Magnetic field perpendicular to cyclotron dees makes particles accelerate in a circle

Radius of circle travelled by particle increases with speed

According to $r = \frac{p}{Bq}$

Cyclotron frequency is given by $f = \frac{Bq}{2\pi m}$

Diagram illustrating any of the above points for linac

Diagram illustrating any of the above points for cyclotron

Magnetic fields can be applied to focus beams without deflecting sideways

7C The particle zoo

7C.1 Particle interactions
1   (a) 1.61 MeV $= 2.58 \times 10^{-13}$ J
      (b) 3.9×10^{20} Hz
2   1.68×10^{-26} kg
3   (a)   In order to conserve momentum
      (b) 1.78×10^{-30} kg $= 1.00$ MeV/c^2
4   (a)   The lone blue track coming from the right
      (b)   It is the straightest track so moves the fastest. Also has no equal but opposite curvature partner track
      (c)   The incoming anti-proton track is the straightest, so all the other smaller particles with their lesser kinetic energies can add up to a total of the p^+/p^- initial mass/energy total.
      (d)   Any red/green track pair with equal and opposite curvature, because their curvature is equal and opposite
      (e)   Each red track has a green counterpart, and these are opposite signs so cancel. Initial charge total of p^+/p^- was zero.
      (f)   As each pair of red and green tracks are mirror images, they start with opposite components of momentum which cancel, leaving only the initial momentum when all are added together.

7C.2 The particle zoo
1   A positron has the same mass as an electron but is positively charged.
2   (a)   Quarks feel the strong nuclear force but leptons do not.
      (b)   Opposite charges
      (c)   Muon has more mass (approx. 207 times)
3   (a)   The predicted top quark has a much larger mass, so they needed more energy to be able to create this more massive particle.
      (b)   Mass $= \frac{175\ GeV}{c^2}$; charge $= -\frac{2}{3}$
4   (a)   The neutrino masses are tiny.
      (b)   The neutrinos' masses increase roughly an order of magnitude for each generation.

7C.3 Particles and forces
1   Proton is uud, neutron is udd, so in beta minus decay, a down quark changes into an up quark.
2   (a)   Baryon is qqq, meson is q$\bar{q}$
      (b)   Hadron can interact via strong nuclear force, lepton cannot
3   The particle that carries the effect of a force between particles
4   Photons are passed back and forth between the two protons

7C.4 Particle reactions
1   (a)   Before: $Q = +15$; after: $Q = +17$ NOT permitted
      (b)   Before: $Q = 0$; after: $Q = 0$ permitted
2   647 m
3     $^{1}_{1}p \rightarrow {}^{1}_{0}n + {}^{0}_{+1}\beta^+ + {}^{0}_{0}\nu_e$
    Demonstration that charge, baryon number and lepton number are conserved. None of the particles involved are strange, so strangeness is conserved at zero.
4   Proposed reaction 1: Q, B, L, S all conserved
    Proposed reaction 2: Q and B all conserved; but L is zero before and -2 (in total) after; and S is zero before and $+1$ (in total) after

7C Exam practice

1   A
2   C
3   B
4   D
5   D
6   QWC (quality of written communication) – work must be clear and organised in a logical manner using technical wording where appropriate; including:
(After X) no tracks / track ceases (at X) / tracks cannot be seen (after X)
(so) uncharged/neutral particles produced
OR only charged particles give tracks
At least one of the correct further events identified (i.e. at the 'V' points) in words or on diagram
Both of the correct further events identified

7   (a) $\frac{2}{3}$ that of a proton or $\frac{2}{3} \times 1.6 \times 10^{-19}$ (C)

    (b)   Mass = 80 MeV/c^2

        Charge = $+\frac{1}{3}$

    (c)   Recognise that M means 10^6
        Convert eV to J or divide by c^2
        e.g. $4 \times 10^6 \times 1.6 \times 10^{-19}$ OR $/9 \times 10^{16}$
        Answer: 7.1×10^{-30} (kg)

    (d)   (i)   Kaon: meson
              Omega: baryon
        (ii) $K^- + p$
              $= K^+ + K^0 + \Omega^-$
        (iii) Kaon plus = $u\bar{s}$
              Kaon neutral = $d\bar{s}$ or $s\bar{d}$
        (iv)   Any five from:
              Momentum conserved
              Charge conserved
              Energy / mass conserved
              $E = mc^2$
              Kinetic energy (of kaon minus) is responsible
              Momentum of three particles after = momentum of kaon before
              Total charge 0 / charge before and after is 0
              Conservation of baryon number, quark number, strangeness

8   (a)   A reference to symmetry
        Quarks in pairs (in the particle generations)
        6 leptons known but only 5 quarks
        (For each quark there has to be an anti-quark will not be credited.)

    (b)   (i)   Same mass
              Opposite charge
        (ii)   Conserve momentum
              Initial (total) momentum is zero

    (c)   (i)   (G)eV units of energy
              ($E = mc^2$ so) $\frac{E}{c} = mc$ = momentum
              OR (G)eV/c^2 is unit of mass
              Momentum is mass $\times$ velocity
         (ii)   Vectors added in sequence after μ_2
              Direction and magnitude of J3 and J4 accurate
        (iii) 94–99 (GeV/c)

(iv)   7 values added together including the value from (iii)
           OR total length of vectors and × 10

(v)   Value in (iv) or 300 divided by 2

(vi)   Any two from:
           Large mass OR top quark (very) heavy
           Large amount of energy required OR issue of providing sufficient energy
           Availability of anti-matter is poor
           Difficulty of storing anti-matter

Topic 8 Thermodynamics

8A Heat and temperature

8A.1 Heat and temperature
1 (a) 300 K
  (b) 100 K
  (c) 373 K
  (d) 15 °C
2 The increase in temperature reduces the thermistor's resistance. This means it takes a smaller proportion of the supplied voltage, increasing the p.d. across the motor, so the motor (cooling fan) increases speed.
3 Change the motor for a voltmeter to record output voltages.
  Add a system for measuring the temperature of the thermistor, such as placing it (electrically insulated) in a water bath.

8A.2 Heat transfer
1 (a) 226 800 J
  (b) 6780 kJ needed, so 3080 s (over 51 minutes)
2 $\Delta E = mc\Delta\theta = 0.5 \times 2100 \times 8 = 8400$ J
  $\Delta E = L\Delta m = 0.5 \times 334\,000 = 167\,000$
  $\Delta E = mc\Delta\theta = 0.5 \times 4200 \times 8 = 16\,800$ J
  Total = 8400 + 167 000 + 16 800 = 192 200 J
3 1085 °C is the melting point of copper, so this additional energy was being absorbed to go towards melting the solid metal.

8A.3 Internal energy
1 (a) 855 m s^{-1}
  (b) 29 K or –244 °C
2 Students' own answers. For example, estimate of 20 °C ($T = 293$ K); assume all molecules are dinitrogen, so $m = 4.676 \times 10^{-26}$ kg; gives $\sqrt{<c^2>} = 509$ m s^{-1}
3 Total KE of molecules in the sample
4 (a) Vertical line for c_0 reaching the peak of the curve
  (b) Two more vertical lines slightly to the right of the peak, correctly labelled
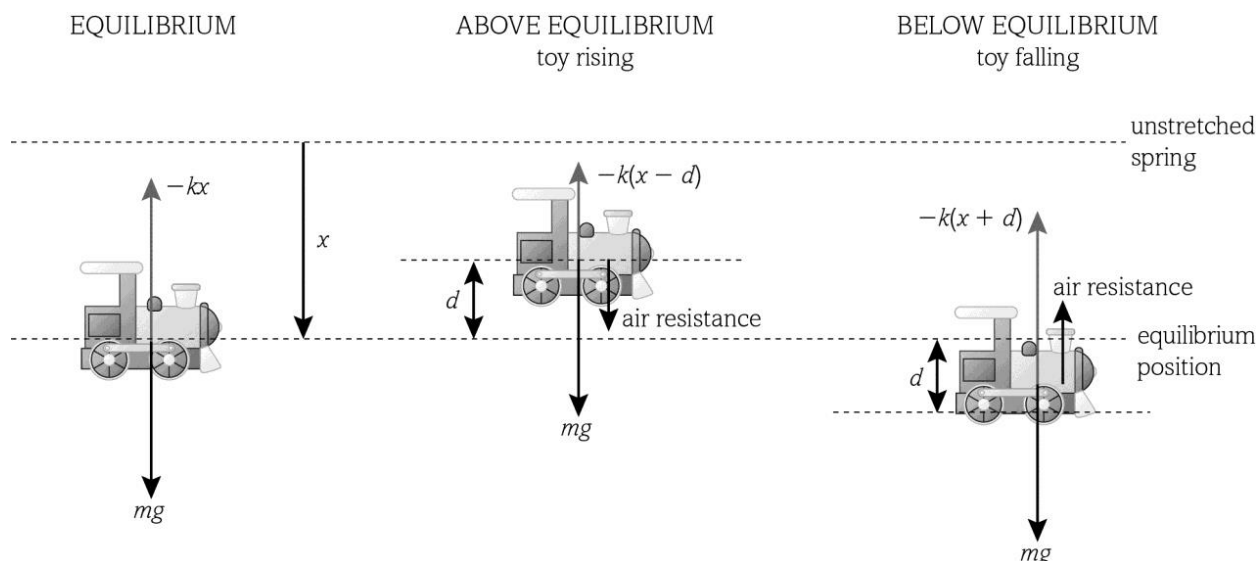
Topic 8 Thermodynamics   Answers
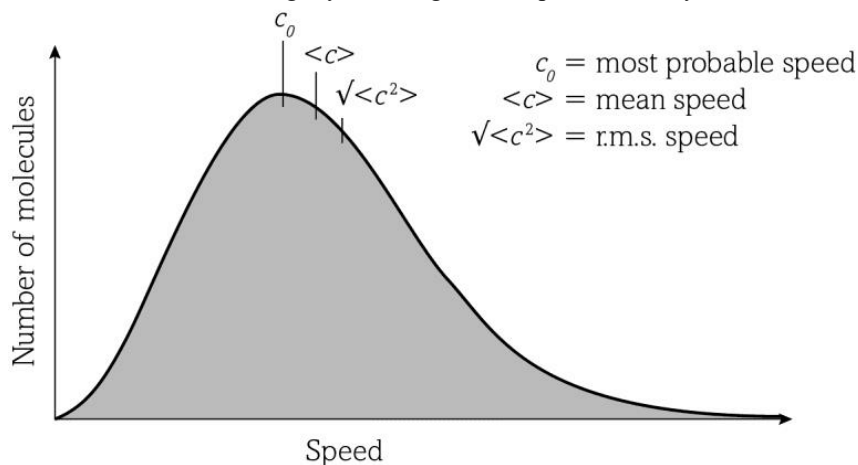
8A.4 Ideal gas behaviour

1   (a)   Students' own answers, after fig A
     (b)   Measure ambient temperature throughout to confirm constant. Vary pressure as independent
            variable and for each pressure, measure volume from scale on glass tube. Plot p vs $\frac{1}{V}$ on graph
     and a straight best-fit line with positive gradient indicates that pressure   is inversely
proportional to volume.
     (c)   E.g. avoiding parallax errors on the glass tube
2   Any refutation of an ideal gas assumption, e.g. air molecules have a finite volume
3   (a)   100 mol
     (b)   495 m s^{-1}
4   Students' own work. For example:
     Place a gas syringe in a water bath, with a thermocouple inside to measure the temperature. Keep at
     constant position (depth) underwater throughout, to confirm constant pressure. Vary temperature as
     independent variable and for each temperature, measure volume from scale on gas syringe. Plot V vs T on
     graph and a straight best-fit line with positive gradient indicates that volume is proportional to temperature.

8A Exam practice

1. A
2. D
3. C
4. (a) Use of $pV = NkT$
   $T = 870$ (K) OR $p = 12.4$ (atmospheres)
   Suggested calculation:

EQUILIBRIUM   ABOVE EQUILIBRIUM   BELOW EQUILIBRIUM
                             toy rising   toy falling

$T = \frac{pV}{Nk} = 12 \times 1.0 \times 10^5$ N m^{-2} $\times 3.00 \times 10^{-4}$ m^3/3 $\times$ $10^{22} \times 1.38 \times 10^{-23}$ J K^{-1} = 869.6 K

   OR

   $p = \frac{NkT}{V} = \frac{3 \times 10^{22} \times 1.38 \times 10^{-28} \text{ J K}^{-1} \times 900 \text{ K}}{3 \times 10^{-6} \text{ m}^3}$

   Therefore, $p = 1.24 \times 10^6$ Pa $= \frac{1.24 \times 10^6 \text{ Pa}}{3 \times 10^{-4} \text{ Pa}} = 12.4$

   (b) QWC (quality of written communication) – work must be clear and organised in a logical manner
   using technical wording where appropriate; including:
   Atoms/molecules would gain energy
   Atoms/molecules would escape from the liquid OR liquid propellant would vaporise / turn into gas
   OR the amount of gas in can would increase
   Pressure would increase due to BOTH temperature/energy increase AND increase in amount of
   gas
   OR pressure would increase more for the same temperature increase
   OR pressure would be greater than 12 atmospheres before 900 K
   The can would explode before 900 K reached

5. (a) Any two from:
   Air behaves as an ideal gas
   Temperature (in the lungs) stays constant
   Implication of no change in mass of gas

   (b) (i) Use of $\rho = \frac{m}{V}$
       Correct answer: 1.3×10^{-4} kg s^{-1}
       Suggested calculation:
       $m = V\rho = 2.5 \times 10^{-4}$ m^3 $\times 1.2$ kg m^{-3} = 3×10^{-4} kg
       $\frac{\Delta m}{\Delta t} = 3 \times 10^{-4}$ kg $\times \frac{25}{60s}$
       $= 1.25 \times 10^{-4}$ kg s^{-1}

       (ii) Use of $\Delta E = mc\Delta\theta$
       Correct answer: 2.2 W

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Suggested calculation:
$P = 1.25 \times 10^{-4}$ kg s^{-1} $\times$ 1000 J kg^{-1} K^{-1} $\times$ (37.6 − 20.0) K = 2.2 W

6   (a)   Temperature (of gas)
           Mass of air/gas OR number of atoms/molecules/moles of air/gas

     (b)   Assumption: idea that volume occupied by trapped air $\propto$ length of air in tube
           (e.g. volume = cross-sectional area $\times$ length)
           pL = a constant OR if p doubles, L halves
           At least 2 pairs of p, L values correctly read from graph
           Readings show that pL = 4500 (kPa cm) ($\pm$ 100 kPa cm)
           OR readings show that p doubles when L is halved
           Suggested calculation:
           p = 400 kPa, L = 11.0 cm; pL = 400 $\times$ 11.0 = 4400
           p = 200 kPa, L = 23.0 cm; pL = 200 $\times$ 23.0 = 4600

     (c)   Use of $pV = NkT$
           Convert temperature to kelvin
           $N = 8.4 \times 10^{20}$
           Suggested calculation:
           $N = \dfrac{450 \times 10^3 \text{ Pa} \times 0.10 \text{ m} \times 7.5 \times 10^{-5} \text{ m}^2}{1.38 \times 10^{-23} \text{ J K}^{-1} \times (273 + 20) \text{ K}} = 8.35 \times 10^{20}$

     (d)   (i)   No change
           (ii)   Similar curve
                  Shifted higher OR shifted to the right
                  (An annotated diagram can score full marks.)

7   (a)   Circuit showing power supply unit (psu), heater, ammeter and voltmeter in parallel with heater
     (b)   Any six from:
           Start below and finish above room temperature
           Measure the p.d. (voltage) and current
           At the start and at the end and find the average
           Switch off current and measure highest temperature reached
           Insulate block
           Measure mass of block (and heater)
           (Put oil into holes to help) good thermal contact between heater, thermometer and block
           Use stop clock to measure time of current flow
           Calculate energy by multiplying voltage by current by time
           Draw appropriate graph and find gradient
           Use gradient correctly to find c

8   (a)   Use of $pV = NkT$
           Convert temperature to K
           Number of breaths = 135
           Suggested calculation:
           $N = \dfrac{pV}{kT} = \dfrac{1.05 \times 10^5 \text{ Pa} \times 6.55 \times 10^{-2} \text{ m}^3}{1.38 \times 10^{-23} \text{ J K}^{-1} \times (273 + 22) \text{ K}}$
           Number of breaths $= \dfrac{1.69 \times 10^{24}}{1.25 \times 10^{22}} = 135$

     (b)   Use of $pV = NkT$
           $p = 1.08 \times 10^5$ Pa
           Suggested calculation:
           $p_2 = p_1 \dfrac{T2}{T1}$
           $p_2 = 1.05 \times 10^5 \dfrac{(273 + 30)}{(273 + 22)}$
           $= 1.078 \times 10^5$ Pa

     (c)   (Average) kinetic energy of molecules/atoms is greater OR molecules/atoms move faster
           Collision rate with walls of container is greater; there is more momentum/impulse (exchanged)
           per collision
           OR the rate of change of momentum is greater
           Therefore a greater force on the container walls

Topic 9 Nuclear Decay   Answers   **P** Pearson

Topic 9 Nuclear decay

9A Radioactivity

9A.1 Nuclear radiation
1   Students' own answers: should include comparisons of penetrating power, ionising ability, hazards, structures
2   0.46 Bq
3   Alpha radiation is blocked by a surface layer of dead skin so cannot penetrate to healthy tissue. Contamination on hand may be passed into mouth from hands and then is emitting alpha internally.
4   Cornwall generally has the highest background radiation level in Great Britain.
5   Description of experiment with different absorbers to selectively block each type of radiation and compare corrected count rates for each. Must mention background measurement and subtraction from each main reading.

9A.2 Rate of radioactive decay
1   (a) 1.37×10^{-11} s^{-1}
      (b) 7.63×10^{-10} s^{-1}
      (c) 4.15×10^{-9} s^{-1}
2   5.4 billion atoms
3   6 hours
4   Half-life is inversely proportional to decay constant.
5   The graph in fig D has a gradient of 0.0091 giving a half-life of 76 s.

9A.3 Fission and fusion
1   Proton: 1.505×10^{-10} J
      Neutron: 1.507×10^{-10} J
      Electron: 8.19×10^{-14} J
2   1.98×10^{-11} J (124 MeV)
3   (a)   7.3 MeV
      (b)   Binding energy per nucleon goes up by 0.6 MeV
      (c) $E_k = 2.07 \times 10^{-15}$ J; rms speed = 788 000 m s^{-1}
4    $X = 95$
5   1.15×10^9 J
6   173 MeV
7   Both fission and fusion products have higher binding energy per nucleon than the starting nuclei. This means that they are more tightly bound so there is less mass per nucleon. This drop in mass is released as energy.

9A Exam practice
1   A
2   B
3   A
4   D
5   (a)   Use of $\lambda = \frac{\ln 2}{t_{1/2}}$ 2
             $\lambda = 1.22 \times 10^{-4}$ (yr^{-1}) ($\lambda = 3.86 \times 10^{-12}$ (s^{-1}), $\lambda = 2.31 \times 10^{-10}$ (min^{-1}))
             Use of $A = A_0 e^{-\lambda t}$
             $t = 950$ (yr) (if $\lambda = 1.2 \times 10^{-4}$, then $t = 960$ (yr))
             Suggested calculation:
             $\lambda = \frac{0.693}{5700 yr} = 1.22 \times 10^{-4}$ yr^{-1}
             14.7 s^{-1} = 16.5 s^{-1} × $e^{-1/22x10^{-4}yr^{-1}xt}$

$$t = \frac{ln\left(\frac{14.7\,s^{-1}}{16.5\,s^{-1}}\right)}{-1.22 \times 10^{-4}\,yr^{-1}} = 947\ yr$$

(b)   Initial value of count rate should be bigger than 16.5 min^{-1}
OR greater count rate from living wood in the past (e.g. A/A_0 smaller)
OR initial value of count rate underestimated in the calculation
OR initial number of undecayed atoms greater (e.g N/N_0 smaller)
Age of sample has been underestimated
OR ship is older than 950 yr
OR sample has been decaying for a longer time

6   (a)   (i)   Use of $m = 1.67 \times 10^{-27}$ kg
Use of $\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$
$c_{rms} = 2800$ (m s^{-1})
Suggested calculation:
$\langle c^2\rangle = \frac{3kT}{m} = \frac{3 \times 1.38 \times 10^{-23}\ J\,K^{-1} \times 310\ K}{1.0087 \times 1.66 \times 10^{-27}\ kg}$
$= 7.66 \times 10^6$ m^2 s^{-2}
$c_{rms} = \sqrt{(7.66 \times 10^6\ m^2\ s^{-2})} = 2.77 \times 10^3$ m s^{-1}

(ii) $^{235}_{92}U + \,^1_0n \rightarrow \,^{236}_{92}U \rightarrow \,^{138}_{55}Cs + \,^{96}_{37}Rb + 2 \times \,^1_0n$
Nucleon, proton numbers correct (236, 55)
Number of neutrons correct (2)

(iii)   Calculation of mass defect
Use of 1 u = 931.5 MeV
Use of fission rate $= \frac{power\ output}{energy\ per\ fission}$
Fission rate $= 8.8 \times 10^{19}$ s^{-1}
Suggested calculation:
$\Delta m = (235.0439 - 137.9110 - 95.9343 - 1.0087)$
$\Delta m = 0.1899 \times 1.66 \times 10^{-27}$ kg $= 3.15 \times 10^{-28}$ kg
$\Delta E = (3 \times 10^3\ m\ s^{-1})^2 \times 3.15 \times 10^{-28}$ kg $= 2.84 \times 10^{-11}$ J
Fission rate $= \frac{2.5 \times 10^9\ W}{2.84 \times 10^{-11}\ J} = 8.8 \times 10^{19}$ s^{-1}

(b)   (i)   QWC (quality of written communication) – work must be clear and organised in a logical manner using technical wording where appropriate; including:
Very high temperatures ($>10^7$ K) needed
To overcome electrostatic repulsion / forces
Nuclei come close enough to fuse / for strong (nuclear) force to act
Very high densities needed
(Together with high nuclei speeds) this gives a sufficient collision rate
(Very high) temperatures lead to confinement problems
Contact with container causes temperature to fall (and fusion to cease)
(Max three from first 5 marking points)

(ii)   X is a proton

(iii)   Any two from:
(Hydrogen) fuel for fusion is (virtually) unlimited whereas fission relies upon (uranium) a relatively limited resource
Fusion results in few radioactive products, but radioactive products produced in fission present significant disposal problems
For a given mass of fuel, the energy released by fusion is greater than the energy released by fission

7   (a)   Record background count (rate)
Place thick aluminium / thin lead between source and detector
OR distance greater than 25 cm between source and detector
Count rate detected above background

(b)   Keep distance between the source and detector constant
Any four from:

- Record count (rate) for different thicknesses
- Record count for a specified time
- Subtract background count
- Take several readings at each thickness
- Measure thickness with micrometer screw gauge / vernier callipers

Keep people away from source / use tongs to handle source / use tongs to handle lead sheets / ensure source held securely

(c) $\ln A = -\mu x + \ln A_0$
        AND identify $-\mu$ as gradient

(d)   Corrected count rate to at least 3 sf and with correct units
        AND $\ln A$ to at least 3 sf and with correct units
        Axes labelled for suitable graph
        Suitable scales
        Plots
        Line

(e)   Triangle base at least 40 small squares
        AND correct calculation of gradient
        $\mu = 0.050$ to 0.052 mm^{-1} with unit and 2–3 sf
        Suggested calculation:
        $\frac{(5.40 - 6.86)}{(28.8 - 0)} = 0.0507$ mm^{-1}

8   (a)   The binding energy per nucleon for ^{4}He is greater/higher/larger (than other small nuclei)
            OR the binding energy per nucleon for ^{4}He is (relatively) large/high
            (Hence) the energy released by the nucleus is greatest for alpha decay
            OR the ^{4}He nucleus is the most stable (of the small nuclei)

     (b)   The idea that some massive/heavy nuclei can undergo (induced) fission
            OR massive nuclei can be made to split into smaller nuclei
            (The graph shows that) massive/heavy nuclei have less binding energy (per nucleon) than the (less massive) nuclei produced in the fission
   (Hence) energy is released in the fission

Topic 10 Oscillations   Answers   Pearson

Topic 10 Oscillations

10A Oscillations

10A.1 Simple harmonic motion (SHM)

1 (a) Equilibrium, mg balanced with kx; above equilibrium, mg + air resistance > $k(x − d)$; below equilibrium, mg < air resistance + $k(x + d)$
NB the direction of air resistance depends on the exact moment chosen.

EQUILIBRIUM   ABOVE EQUILIBRIUM   BELOW EQUILIBRIUM
toy rising   toy falling
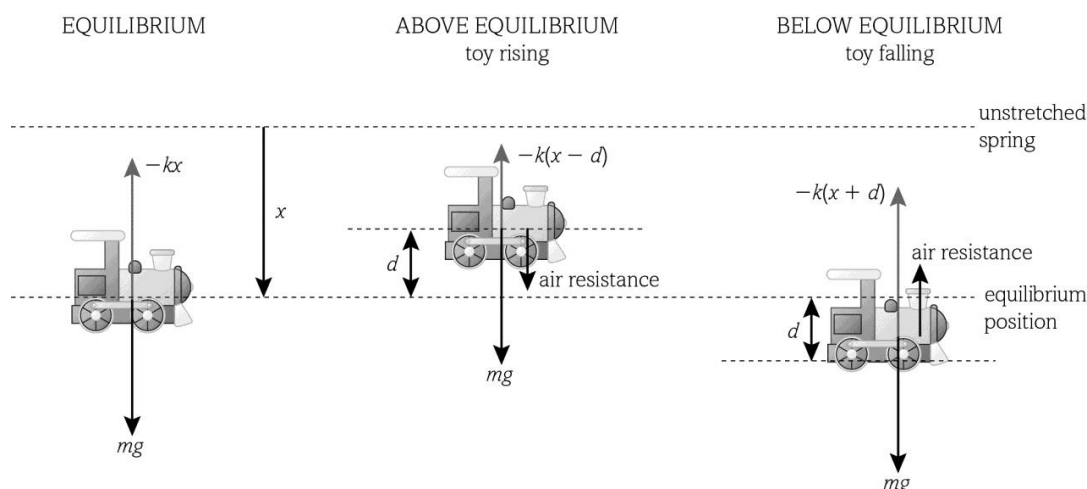
   (b) Air resistance is variable.
2 (a) 4.2 s
   (b) Keep still; take measurements over a large number of swings
3 (a) Repeating isochronous oscillations caused by a restoring force which is proportional to the displacement
   (b) 1.55 m
   (c) 3 cm
   (d) 6 m s^{-1}
   (e) Sine curve shape shifted from fig D by quarter of a cycle, so v–t graph is zero at time zero, −6 at 2 s, zero at 4 s, +6 at 6 s, zero at 8 s and −6 at 10 s (compare with fig B in 10A.2).

10A.2 SHM mathematics

1 4.4 rad s^{-1}
2 Angular velocity is rounded to 5.24 and then used in further calculations. Without rounding, $x = 0.400$ m (3.5% difference), $v = 3.63$ m s^{-1} (1.2% difference), and $a = 11.0$ m s^{-2} (3.8% difference). With 3 sf, should aim to keep % rounding errors below 1%.
3 $x = −3.3$ cm; $v = −0.54$ m s^{-1}; $a = 6.68$ m s^{-2}
4 $x_6 = 0.075$ m; $v_6 = −0.14$ m s^{-1}; $a_6 = −0.37$ m s^{-2}

10A.3 SHM energy

1 8 seconds: E_k = zero; $E_{kmax} = 1.85 \times 10^{-3}$ J
2 GPE → KE + GPE → EPE + KE + GPE → EPE → EPE + KE + GPE → KE + GPE → GPE and repeat
In real life, energy is lost from the system through air resistance, and stresses within the bungee material.
3 Intermolecular stresses in the string cause a heating effect, slowing the bob as kinetic energy transfers to heat.
4 Tyre lift is actually 1.35 m, which is nearly 23% larger than the calculated height.

10A.4 Resonance and damping

1   Students' own answers

2   At that speed, engine frequency is at a resonant / natural frequency for that part of the dashboard.

3   Significant damping, perhaps by adding a foam pad, could dissipate the vibration energy. Alternatively, altering the natural frequency of the dashboard part, perhaps by taping a weight to it, would avoid the resonance occurring. This could also be achieved by never driving fast enough to cause resonance!

4   Underdamping reduces amplitude of oscillations a little with each cycle. Overdamping stops oscillations entirely by returning to equilibrium very slowly. Critical damping allows nearly normal oscillation speed back to the equilibrium position, where the system is stopped.

5   The damper reduces oscillation amplitude, reducing stresses on the bridge girders.

6   Body cavities have resonant frequencies and there is a particularly strong one in the chest at around 7 Hz. The music causes resonance of the dancer so they vibrate more than anticipated for the volume of the music.

Topic 10 Oscillations
Answers
P Pearson

10A Exam practice

1   C
2   B
3   A
4   A
5   (a)   Acceleration is:
          •   (directly) proportional to displacement from equilibrium position
          •   (always) acting towards the equilibrium position OR idea that acceleration is in the opposite direction to displacement
       OR
       Force is:
          •   (directly) proportional to displacement from equilibrium position
          •   (always) acting towards the equilibrium position OR idea that force is a restoring force, e.g. 'in the opposite direction'
       (An equation with symbols defined correctly is a valid response for both marks:
       e.g. $a \propto -x$ OR $F \propto -x$)

      (b)   (i)   Amplitude = 2.3 m
                    Time period = 24 hours
                    (24 hours = 86 400 s)
                    Suggested calculation:
                    Amplitude = $\frac{(6.1 \text{ m} - 1.5 \text{ m})}{2} = 2.3$ m
                    Period = $\frac{(48 \text{ h} - 0 \text{ h})}{2} = 24$ h

          (ii)   Use of $\omega = \frac{2\pi}{T}$
                    Use of $v = (-)A\omega \sin \omega t$ ($v = \omega A_{max}$)
                    $v_{max} = 0.60$ m h^{-1}
                    Suggested calculation:
                    $\omega = \frac{2\pi}{T} = \frac{2\pi \, rad}{24 \, h} = 0.262$ rad h^{-1}
                    OR
                    Calculate gradient with a max $\Delta t = 12$ hours, and max $\Delta x = 6$ m
                    Rate of change of depth in range (0.54–0.66) m h^{-1}
                    Rate of change of depth in range (0.57–0.63) m h^{-1}
                    Suggested calculation:
                    Rate of change of depth = $\frac{(6.5 - 1.0)}{(11.0 - 1.5)} = 0.57$

          (iii)   Graph with correct shape (minus sine curve, at least 30 hours)
                    Same time period as graph given, constant amplitude

6   (a)   Force (or acceleration):
          •   (directly) proportional to displacement
          •   always acting towards the equilibrium position

      (b)   Use of $\omega = 2\pi f$ OR $\omega = \frac{2\pi}{T}$
            Use of $v = A\omega \sin \omega t$ OR $v = A\omega$
            $v = 0.35$ m s^{-1}
            Suggested calculation:
            $\omega = 2\pi$ rad $\times \frac{10}{4.5s} = 14.0$ rad s^{-1}
            $v = 2.5 \times 10^{-2}$ m $\times 14.0$ s$^{-1} = 0.35$ m s^{-1}

      (c)   Any three from:
          Node at fixed end or antinode at free end
          Distance from node to antinode $= \frac{\lambda}{4}$
          As (vibrating) length increases, wavelength increases
          Reference to $v = f\lambda$
          The shorter the ruler the higher the frequency

7   (a)   Wood is not magnetisable/ferromagnetic
      (b)   Measure more than one T

Repeat for mean

Use of marker, must state where placed or that it helps in counting or timing

(c) Oscillations die away more quickly

(d) (i) Link both axes with variables and $y = mx (+ c)$

OR link k with gradient

State that variables are directly proportional OR state that $c = 0$

(ii) Data correct to 2–3 d.p. with unit

Axes and labels

Scales

Plots

Line

I/A	Mean T/s	$1/T^2$/s^{-2}
0	1.23	0.66
1.00	0.827	1.46
2.00	0.673	2.21
3.00	0.581	2.96
4.02	0.520	3.70
5.01	0.475	4.43

(iii) Any two from:

Graph is a straight line

Graph does not pass through origin OR $c = b \neq 0$

Magnet oscillates at zero current

8   Any six from:

Damped oscillations suffer a loss in energy in each oscillation.

This reduces the amplitude.

This must be caused by an external force

which may come from a friction force, or internal stresses in the material.

The friction force can be provided by plastic deformation of a ductile material.

Underdamping will have the oscillator complete many oscillations, which decrease in amplitude exponentially.

Overdamping will reduce the amplitude to zero in less than one cycle.

If the oscillator returns to equilibrium as quickly as possible without further oscillations, this is critical damping.

Topic 11 Astrophysics and cosmology

11A Gravitational fields

11A.1 Gravitational forces
1. The gravitational field strength of Earth is 9.81 N kg^{-1} at its surface.
2. 6.0×10^{-68} N
3. 2.0×10^{20} N
4. 1.5×10^{11} m
5. Straight-line graph with positive gradient, passing through the origin. Correctly labelled axis (does not need units on a sketch graph).

11A.2 Gravitational fields
1. Gravitational field strength 7.5 N kg^{-1}
   Gravitational potential 5.5×10^{7} J kg^{-1}
2. (a) H atom: $F = 8.2 \times 10^{-8}$ N
   (b) Pluto: $F = 4.94 \times 10^{16}$ N
   The Solar System force is $10^{23} \times$ stronger for a system which is $10^{23} \times$ larger.
3. 3.0×10^{-5} kg
4. 3.46×10^{8} m

11A Exam practice
1. C
2. A
3. D
4. B
5. $g = \dfrac{GM}{r^2}$

   Correct substitution into $g = \dfrac{GM}{r^2}$

   $r_E = \dfrac{GM_E}{r_{E^2}}$; $g_m = \dfrac{GM_m}{r_{m^2}}$

   $\dfrac{r_E}{r_m} = 3.7$

   (Correct inverse ratio i.e. $\dfrac{r_m}{r_E} = 0.27$, scores full marks)

   Suggested calculation:

   $\therefore \dfrac{g_E}{g_m} = \dfrac{\frac{GM_E}{r_E^2}}{\frac{GM_m}{r_m^2}} = \dfrac{M_E}{M_m} \times \dfrac{r_m^2}{r_E^2}$

   Therefore, $6 = 81 \times \dfrac{rm^2}{rE^2}$

   Therefore, $\dfrac{r_E}{r_m} = \sqrt{81/6} = 3.67 \approx 3.7$

6. (a) $F = mg$ and $F = (-)\dfrac{GmM}{r^2}$

   Equate and cancel m on either side

   (b) Substitute into $g = \dfrac{GM}{r^2}$ to obtain $g = 9.78$ N kg^{-1}

   Suggested calculation:

   $g = \dfrac{GM}{r^2} = \dfrac{6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2} \times 5.97 \times 10^{24}\ \text{kg}}{(6.38 \times 10^{6}\ \text{m})^2} = 9.783$ N kg^{-1}

7. (a) Calculation of time period
   Use of $v = \dfrac{\Delta s}{\Delta t}$ or $\omega = \dfrac{2\pi}{T}$
   Use of $a = \dfrac{v^2}{r}$ or $a = r\omega^2$
   Correct answer
   Suggested calculation:

$$T = \frac{24 \times 60 \times 60 \text{ s}}{15} = 5760 \text{ s}$$

$$v = \frac{2\pi r}{T} = \frac{2\pi \times 6.94 \times 106 \text{ m}}{5760 \text{ s}}$$

$$= 7.57 \times 10^3 \text{ m s}^{-1}$$

$$a = \frac{v^2}{r} = \frac{(7.6 \times 103 \text{ m s}^{-1})^2}{6.94 \times 10^6 \text{ m}}$$

$$= 8.26 \text{ m s}^{-2}$$

OR

$$\omega = \frac{2\pi}{T} = \frac{2\pi}{5760 s} = 1.09 \times 10^{-3} \text{ m s}^{-1}$$

$$a = r\omega^2 = 6.94 \times 10^6 \times (1.09 \times 10^{-3})^2 = 8.26 \text{ m s}^{-2}$$

(b)   *mg* equated to gravitational force expression

$g (= a) = 8.3$ ms^{-2} substituted

Correct answer

Suggested calculation:

$$mg = \frac{GMm}{r^2}$$

Therefore, $8.3 \text{ m s}^{-2} = \frac{6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2} \, M}{(6.94 \times 10^6 \text{ m})^2}$

Therefore, $M = \frac{8.3 \text{ m s}^{-1} \times (6.94 \times 10^6 \text{ m})^2}{6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}}$

$$= 6.0 \times 10^{24} \text{ kg}$$

8   (a)   The gravitational field strength decreases

OR the (gravitational) force on the satellite/object/mass decreases

It is a centripetal force (and not a centrifugal force)

The satellite is accelerating and so is not in balance

(b)   (i)   See $\frac{mv^2}{r} = \frac{GmM_E}{r^2}$ OR $m\omega^2 r = \frac{GM_m}{r^2}$

$$\therefore v^2 = \frac{GM_E}{r} \text{ OR } v = \sqrt{\frac{GM_E}{r}}$$

GM_E is constant (and so v decreases as r increases)

OR $v^2 \propto \frac{1}{r}$ OR $v \propto \frac{1}{\sqrt{r}}$

(ii)   State $T = \frac{2\pi}{\omega}$ and $\omega = \frac{v}{r}$ OR $T = \frac{s}{v}$ and $s = 2\pi r$

Hence $T = \frac{2\pi r}{v}$ (so smaller v leads to a larger value of T)

(c)   Use of $T = \sqrt{\frac{4\pi^2 r^3}{GM}}$

$T = 5530$ s (92 minutes)

Suggested calculation:

$$T = \sqrt{\frac{4\pi^2 r^3}{GM}} = \sqrt{\frac{4\pi^2 (6360\,000 \text{ m} + 400\,000 \text{ m})^3}{6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2} \times 5.8 \times 10^{24} \text{ kg}}} = 5530 \text{ s}$$

(d)   Any two from:

As radius decreases:

There is a transfer of gravitational potential energy to kinetic energy

Sum of kinetic and gravitational potential energy decreases

OR satellite does work against frictional forces

OR transfer of kinetic energy of satellite to thermal energy

OR heating occurs

9   (a)   Gravitational field is a region where a mass experiences a force so $g = \frac{F}{M}$

    (b) $\frac{1}{r}$ shape

        negative potential values
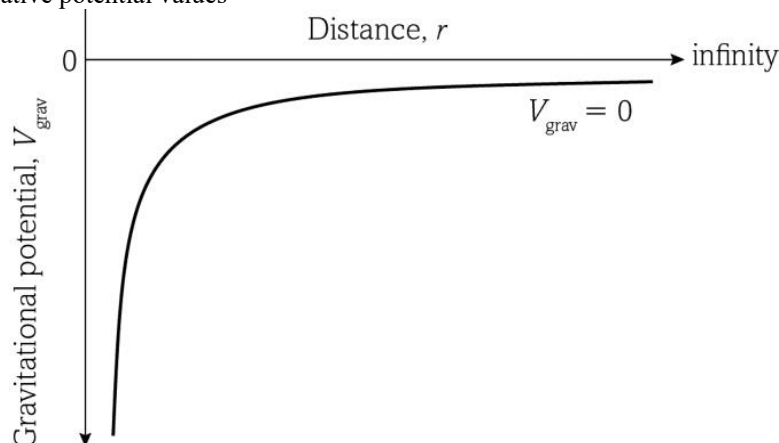
    (c)   (i) 5.9×10^8 J kg^{-1}

        (ii) 6.3×10^7 J kg^{-1}

10   Any six from:

Gravity is only attractive

Electric forces can be attractive or repulsive

Gravitational fields generated by mass; electric fields generated by charge

Gravitational fields cause forces on masses; electric fields cause forces on charged objects/particles

Both follow inverse square law in the forces they cause at a distance between two masses or charges

Both follow inverse square law in the field strength at a distance from the mass or charge

The potential is a scalar quantity for both

The constant of proportionality for electric fields, ε, depends on the medium, but G is constant

11B Space

11B.1 Starshine
1 1.82×10^{28} W
2 (a) 5.0×10^{-7} m
   (b) Atmospheric absorption
3 1.35×10^{-7} m
4 Canopus: $\lambda_{max} = 490 \times 10^{-9}$ m, therefore, $T = 5920$ K; Rigel: $\lambda_{max} = 275 \times 10^{-9}$ m, therefore, $T = 10\ 500$ K

11B.2 Stellar classification
1 1.2×10^{57} protons; means 4.2×10^{39} every second
2 Students' own answers, after fig D
3 2.7×10^{23} N kg^{-1}; which is 2.7×10^{22} times larger than Earth's gravitational field strength
4 (a) Students' own answers, after fig F
   (b) On same HR diagram, start in top middle (or marked on supergiants region) move to the right and then stop when supernova removes it from HR diagram.
5 Helium nuclei have a particularly stable grouping, with higher binding energy per nucleon than other combinations.
6 (a) This would require energy input overall.
   (b) In a supernova explosion, there is a lot of energy that can be added to nuclei to produce the heavy elements.

11B.3 Distances to the stars
1 2.7×10^5 AU
2 (a) 1.14×10^{17} m
   (b) 12 ly
   (c) 3.68 pc
   (d) 7.56×10^5 AU
3 7.57×10^{18} m
4 (a) 1.02×10^{-7} W m^{-2}
   (b) 2.64×10^{-5} m
5 Much less energy, at generally longer wavelengths

11B.4 The age of the Universe
1 Galaxies moving away from us, meaning that the Universe is expanding
2 (a) On approach, Doppler shift raises frequency; as car recedes, frequency is reduced by Doppler effect
   (b) Drivers are moving at same speed relative to engine, so not approaching or receding from source of sound waves
3 (a) 669.411 nm
   (b) 84.5 Mpc
4 10–20 Gyr

11B.5 The fate of the Universe
1 The actual motion of the galaxies within the Universe is not precisely known, and adds or subtracts from the red shift.
   Distance measurements have long been very difficult to get accurate, and this will affect the best-fit line on the graph of v against d and thus affect the value of H_0.
2 Its exact value would determine the fate of the Universe: continual expansion; deceleration to a maximum size Universe, or deceleration and then contraction into a Big Crunch.
3 Galaxies are not bright enough for the speed at which they rotate so must contain some non-luminous matter.
   Gravitational lensing has been studied in detail and observed in regions where no galaxies exist.

11B Exam practice

1   A

2   C

3   D

4   D

5   (a)   Use of $\frac{L}{4\pi d^2}$ OR $F \propto \frac{1}{d^2}$

$\frac{F_{Mars}}{F_{Earth}} = 0.43$

Suggested calculation:

$F = \frac{L}{4\pi d^2}$

$F = \frac{F_{Mars}}{F_{Earth}} = \frac{d^2_{Earth}}{d^2_{Mars}} = [\frac{1.5 \times 10^{11}\ m}{2.3 \times 10^{11}\ m}]^2 = 0.43$

    (b)   Observation that (radiation) flux is approximately half that on the Earth OR Earth has approximately double the (radiation) flux of Mars

Comment that makes reference to energy/intensity/number of photons

OR comparison with polar or deep sea regions on the Earth

OR reference to a thinner atmosphere (allowing a greater fraction of photons get through to surface)

6   QWC (quality of written communication) – work must be clear and organised in a logical manner using technical wording where appropriate; including:

Parallax:

The star is viewed from two positions at 6-month intervals OR the star is viewed from opposite ends of its orbit diameter about the Sun

The (change in) angular position of the star relative to fixed/distant stars is measured

The diameter/radius of the Earth's orbit about the Sun must be known and trigonometry is used (to calculate the distance to the star)

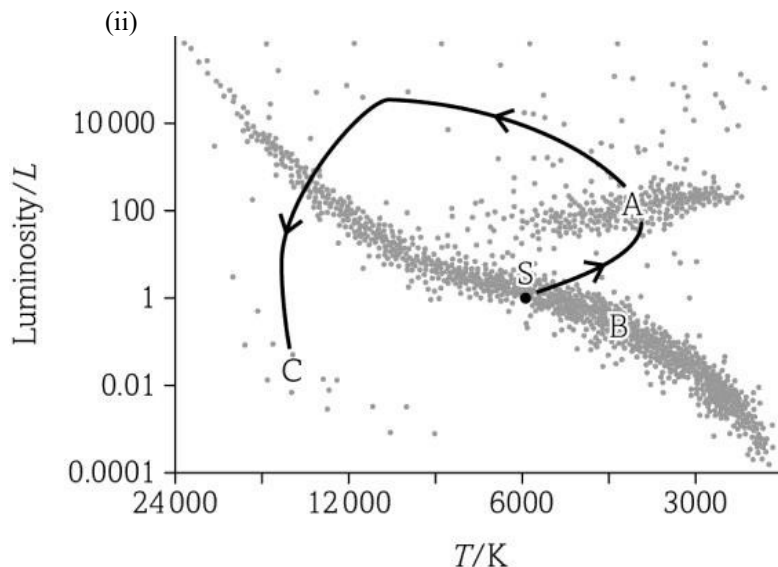(Marks may be obtained with the aid of a suitably annotated diagram, e.g. as below:
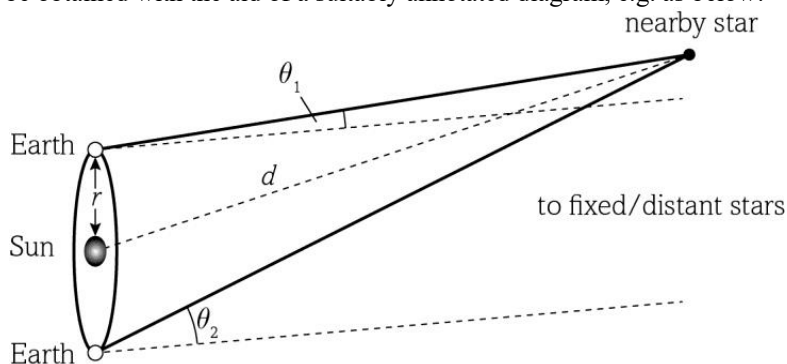
Standard candle:

Flux / brightness / intensity of standard candle is measured

Luminosity of standard candle is known

Inverse square law is used (to calculate distance to standard candle)

7   (a)   (i)   A = red giants OR giants
B = main sequence
C = white dwarfs OR dwarfs

(ii)

S → A correctly marked (straight line or curve starting at S going near A)
A → C correctly marked (straight line or curve from near A, near to C but can go beyond C)

(b)   We determine the star's
- temperature T (from Wien's law)
- luminosity L (from the H–R diagram)
- (then) r is calculated using (Stefan's law) $L = 4\pi r^2 \sigma T^4$ OR $L = A\sigma T^4$

8   (a)   Calculate gradient of line
Identify gradient with H_0 OR use of $v = H_0 d$ for a point on the line
Use of $t = \frac{1}{H0}$
$t = 4.5 \times 10^{17}$ s
Alternative method:
Pair of d, v values read from the line
Values chosen from the upper end of the line
Use of $t = \frac{d}{v}$
$t = 4.5 \times 10^{17}$ s ($\pm 0.3 \times 10^{17}$ s)
($t = 1.4 \times 10^{10}$ yr ($\pm 0.1 \times 10^{10}$ yr))
Suggested calculation:
$H_0 = $ gradient $\frac{(11\,000 - 0) \times 103\ m\ s^{-1}}{(50 - 0) \times 1023\ m}$
$= 2.2 \times 10^{-18}$ s^{-1}
$t = \frac{1}{H_0} = \frac{1}{2.2 \times 10^{-18}\ s^{-1}} = 4.5 \times 10^{17}$ s

(b)   QWC (quality of written communication) – work must be clear and organised in a logical manner using technical wording where appropriate; including:
Measure wavelength of light (from the galaxy)
Compare it to the wavelength for a source on the Earth
Reference to spectral line OR line spectrum
Reference to Doppler effect / shift OR red shift
v is found from:
fractional change in wavelength equals ratio of speed of source to speed of light
OR reference to $\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$ with terms defined
OR reference to $z = \frac{v}{c}$ with terms defined

(c)   QWC (quality of written communication) – work must be clear and organised in a logical manner

using technical wording where appropriate; including:

Any three from:

(Due to the) difficulty in making accurate measurements of distances to galaxies

Hubble constant has a large uncertainty

OR age $= \frac{1}{H_0}$ may not be valid as gravity is changing the expansion rate

Because of the existence of dark matter

Values of the (average) density/mass of the Universe have a large uncertainty

(Hence) measurements of the critical density of the Universe have a large uncertainty

Dark energy may mean we don't understand gravity as well as we thought we did (so it's hard to predict how gravity will determine the ultimate fate)

9   (a)   (i) $\sigma = 3.54 \times 10^{-8}$ (W m^{-2} K^{-4}) to 2–3 sf

Suggested calculation:

$\sigma = \frac{23.5\ W}{2 \times 10^{-5}\ m^2 \times (2400\ K)^4} = 3.54 \times 10^{-8}$ (W m^{-2} K^{-4})

(ii)   Add 3 percentage uncertainties

%U = 23(%)

Suggested calculation:

%U = 2% + 5% + 4 × 4% = 23%

(iii)   Uses value in (i) to calculate % Difference = 38(%)

Suggested calculation:

%D $= \frac{(5.67 - 3.54) \times 100\%}{5.67} = 38\%$

(iv)   %D > %U so the result is not reliable (use values from (ii) and (iii))

OR

The % difference is not explained by the % uncertainty in the readings

(so the result is not reliable)

(b)   (i)   Find value for intercept (on ln *L* axis)

Divide anti-log of this value by *A*

(ii)   The temperature of the bulb is (very) much greater than room temperature.