Physics Solutions (Calculations)

Section A: Multiple Choice

1. **Answer:** kg m^2 s^{-2}

Working: Joules and Newtons are derived SI units not base units
Consider kinetic energy: $E = \frac{1}{2} m v^2$
Units are then, kg * $(m\ s^{-1})^2$
= kg m^2 s^{-2}

2. **Answer:** 1.9 s

Working: Using SUVAT: s = 49, u = ?, v = 26, a = 0.8, t = ?
$v = u + at \rightarrow u = v - at$
$s = ut + \frac{1}{2} at^2 \rightarrow s = (v - at)t + \frac{1}{2} at^2 \rightarrow s = vt - \frac{1}{2} at^2$
$49 = 26t - 0.4t^2$
Solving as a quadratic, t = 1.94 or t = 63.1
Only 1.9 is an option (2 s.f.)
(the other solution represents the case where the initial velocity was negative, but this cannot be the case in the context of the question)

3. **Answer:** 0.40 m to the right of the pivot

Working: Let the centre of mass of the plank be at x metres to the right of the pivot. Taking moments about the pivot,
1.2 * 35g + x * 15g = 0.8 * 60g
$42 + 15x = 48 \rightarrow x = 6/15 = 0.4$ m to the right

4. **Answer:** 6400 J

Working: Energy after = energy before - energy lost
Energy after = kinetic energy = ½ * 200 * 9^2 = 8100 J
Energy before = kinetic + potential = ½ * 200 * 5^2 + 200 * 10 * (8-2)
= 14500 J (using g = 10)
Energy lost = 14500 - 8100 = 6400 J

5. **Answer:** Elastic potential energy stored per unit volume of material

Working: Area of graph represents ½ x stress x strain (straight line section: triangular)
Stress = F/A and Strain = x/L
Area = ½ Fx/AL
AL = area x length = volume
½ Fx = ½ * tension * extension = EPE (using E = ½ kx^2)
So the area = EPE / volume
= elastic potential energy stored per unit volume of material

6. **Answer:** 3 kg

Working: Kinetic energy = 150 = ½ * mv^2
Momentum = 30 = mv
150 = ½ * mv * v = ½ * 30 * v
→ v = 10 → 30 = 10m → m = 3 kg

7. **Answer:** 17000 N to the right

Working: Resultant force = rate of change of momentum
= change in momentum in 1 second
Since the oil must flow at a constant rate (conservation of mass),
Oil in = oil out → 5 * 0.6 = v * 0.25 → v = 12
Mass of oil flowing in one second = volume x density
= 5 * 0.6 * 800 = 2400 kg s^{-1}
Change in momentum = 2400(12 - 5) = 16800 = 17000 (2 s.f.)
Direction is to the right since change in momentum is positive

8. **Answer:** 4/5 R

Working: Same material → resistivity is the same in both
Resistance in parallel = 1/(1/X + 1/Y)
In Y: R = pL/A
In X: L is the same, A is 4 times smaller (2^2 scale factor for areas)
So If Y = R, then X = pL/(A/4) = 4 pL/A = 4 R
Resistance = 1/(1/4R + 1/R) = 1/(5/4R) = 4R/5

9. **Answer:** $2I_1 + 4I_3 = 13$

Working: Kirchhoff's second law: the signed p.d. changes in a closed loop is Zero. Using V = IR for the resistors,
In the left loop: +5 (cell), $-I_1R_1$ (resistor 1), $-I_2R_2$ (resistor 2)
So $5 = 2I_1 + I_2$
In the right loop: +8 (cell), $-I_3R_3$ (resistor 3), $-I_2R_2$ (resistor 2)
So $8 = I_2 + 4I_3$
In the outside loop: Be very careful with signs (directions)
+8 (cell), $-I_3R_3$ (resistor 3), $+I_1R_1$ (resistor 1: goes against direction of p.d.), -5 (cell) (pushes p.d. Against the 8 V cell)
So $8 - 4I_3 + 2I_1 - 5 = 0 \rightarrow 4I_3 - 2I_1 = 3$
The only equation not listed is $2I_1 + 4I_3 = 13$
(This equation is obtained by ignoring signs in the outside loop)

10. **Answer:** 32 m

Working: In a transverse wave, a particular particle moves up and down only, not along the rope. In one time period, a particle moves up and down one full amplitude twice.
Time period = 1/f = 1/10 = 0.1 s
Distance in one time period = 4 * amplitude = 4 * 0.04 = 0.16
Cycles = 20/0.1 = 200
Total distance = 200 * 0.16 = 32 m

11. **Answer:** B and C only

Working: A: This is false. Density decreases as temperature increases.
B: This is true as water occupies a larger volume when heated.
C: This is true.
Both of the true statements explain convection currents as the hot (less dense) water rises while the cold (more dense) water sinks.
So the answer is B and C.

12. **Answer:** $1/2\ M\omega_0^2\ (R - r)^2$

Working: Consider the centre of mass of the ring (its centre).
It moves in a path of radius R - r, since it rotates about the centre of the finger (figure 2).
Kinetic energy = $\frac{1}{2}mv^2$ and $v = \omega r$:
$KE = \frac{1}{2} M(\omega_0(R - r))^2 = 1/2\ M\omega_0^2\ (R - r)^2$.

13. **Answer:** 1.50

Working: In the first step, C_3 gets charged.
The charge it stores is $Q = VC = 8 * 1 * 10^{-6} = 8 * 10^{-6}$ C
In the second step, C_3 gets partially discharged.
Using micro units to simplify,
(Q on C_3 / Total Q) = (C of C_3 / C of circuit) using Q = VC
5/8 = 1/C of circuit
Capacitance of circuit = $1 + 1/(1/C_1 + 1/C_2)$
$C_1 = \varepsilon A/d = \varepsilon C_2 \rightarrow$ total $= 1 + 1/(1/\varepsilon + 1) = 1 + \varepsilon/(\varepsilon + 1)$
$8/5 = 1 + \varepsilon/(\varepsilon + 1) \rightarrow 3/5 = \varepsilon/(\varepsilon + 1) \rightarrow 3\varepsilon + 3 = 5\varepsilon$
$\rightarrow 2\varepsilon = 3 \rightarrow \varepsilon = 3/2 = 1.50$

14. **Answer:** 70 Bq

Working: Find out how many half-lives each substance undergoes:
X: 24/4.8 = 5
Y: 24/8 = 3
New activity of X: $320/2^5 = 10$, New activity of Y: $480/2^3 = 60$
Total activity = 10 + 60 = 70 Bq

15. **Answer:** 5.0 litres

Working: Half life = 8*24*60*60 = 691200 s
Using the formula, $\ln(R_0/R) = t \ln(2)/t_{1/2}$,
$\ln(2)/691200 \times 11.5 * 3600 = \ln(2.4 \times 10^5 / R)$
$R = 2.3 \times 10^5$ (count rate of all iodine in blood)
Since activity is proportional to volume,
$115/(2.3 \times 10^5) = 0.0025/V \rightarrow V = 5$ litres

Section B: Standard Questions

16.

a. Sets up equations of motion for each of the boy and girl using SUVAT
Boy: $s - 10 = 11t - ½ * 9.8 * t^2 \rightarrow s = 10 + 11t - 4.9t^2$ [1 mark]
Girl: $s = 10(t - 1.5) - ½ * 9.8 * (t - 1.5)^2 \rightarrow s = 10t - 15 - 4.9(t - 1.5)^2$ [2 marks]
Equates displacements
$10 + 11t - 4.9t^2 = 10t - 15 - 4.9(t - 1.5)^2$ [1 mark]
$10 + 11t - 4.9t^2 = 10t - 15 - 4.9t^2 + 14.7t - 11.025$
$13.72t = 36.04$
$t = 2.63 =$ **2.6 s** (2 s.f.) [2 marks]

b. Substitutes t back into either motion equation
Boy: $s = 10 + 11(2.63) - 4.9(2.63)^2$ [1 mark] = 5.03 = **5.0 m** (2 s.f.) [1 mark]

c. Velocity of the boy's stone = u + at = 11 - 9.8 * 2.63 = -14.77 [1 mark]
Velocity of the girl's stone = u + at = 10 - 9.8 * (2.63 - 1.5) = -1.07 [2 marks]
Relative speed = $|v_1 - v_2|$ = 14.77 - 1.07 = 13.7 = **14 ms^{-1}** (2 s.f.) [1 mark]

d. Any two valid assumptions from:
No air resistance acts on the stones, the boy's stone is released from the height of the ledge / the boy/girl has no size, the stones have no size / the stones are modelled as particles [2 marks]

17.

a. The force is constant
The distance (from Q to P) remains constant [1 mark]
So their product (the torque) is also constant [1 mark]

b. i) The **perpendicular distance** to the line of the force remains **constant**. [1 mark]
The wheel **climbs** the step. [1 mark]

ii) The **perpendicular distance** to the line of the force is **zero**.
No torque so the wheel **remains stationary / does not climb** [1 mark]

iii) Force is cancelled by the horizontal reaction force at Q
No resultant force so the **wheel does not move** [2 marks]

18.

a. i) An object moving at **constant velocity** (or at rest) will continue to do so unless acted on by a **resultant force** [1 mark]

ii) **Rate of energy transfer / rate of work done / (Energy / Time)** [1 mark]

iii) The (thrust) force from the engine **equals** the resistive forces (acting on the car) [1 mark]

b. P = Fv → F = P/v
At maximum speed, F = 48000/40 = 1200 N [1 mark]
Resistive force = 1200 = kv [1 mark] = 40k → k = 30 [1 mark]
At 25 ms^{-1}:
(48000/25) - (30 * 25) = 1250 * a [2 marks]
a = 0.936 → **a = 0.94 ms^{-2}** (2 s.f.) [1 mark]

c. At maximum speed, forces are balanced again
$(48000/v) + 1200g \sin(4) = 30v$ [1 mark]
$48000/v + 821.2 = 30v$ [1 mark]
$30v^2 - 821.2v - 48000 = 0$ [1 mark]
$v = -28.59$ or $v = 55.96$
$v > 0$ so $v = 55.96 = 56\ ms^{-1}$ (2 s.f.) [1 mark]

d. i) 100% x Useful energy out / Total energy in , or
100% x Useful power out / Total power in [1 mark]

ii) Cycles per second = (7000 / 60) * 4 = 466.667 [1 mark]
Energy per second = power = 466.667 * 120 = 56000 [1 mark]
Efficiency = 48000 / 56000 * 100% = 86% [1 mark]

19.

a. At lower temperatures, the number of **mobile charge carriers** in a semiconductor is **low** so they have **high resistance** [1 mark]
At higher temperatures, the energy is **used to free electrons** from the atoms in the semiconductor and allow them to flow
So as the **temperature increases,** the **resistance decreases** [1 mark]

b. Force due to electric field: eV/a [1 mark]
Force due to magnetic field: Bev [1 mark]
$eV/a = Bev \rightarrow V = Bva$ [1 mark]

c. $I = nevA \rightarrow 0.06 = 1.2 \times 10^{23} * 1.6 \times 10^{-19} * v * (0.005 \times 0.0002)$ [2 marks]
$\rightarrow v = 3.125 =$ **$3.1\ ms^{-1}$** (2 s.f.) [1 mark]
$\rightarrow V = 0.04 * 3.125 * 0.005 = 0.000625 =$ **6.3×10^{-4} V** (2 s.f.) [1 mark]

20.

a. Deduces that two consecutive resonances differ by $\lambda/2$ [1 mark]
$0.821 - 0.489 = \lambda/2$ [1 mark] $\rightarrow \lambda = 0.664$ m [1 mark]
$V = f\lambda = 500 * 0.664 =$ **332 ms^{-1}** (3 s.f.) [1 mark]

b. i) $\lambda = 66.4$ cm and harmonics occur at $L = (2n - 1)\lambda/4$ [1 mark]
$0.489 = (2n - 1)*0.664/4 \rightarrow n = 1.97$
At n = 2, ideal resonance length is $3(66.4)/4 = 49.8$ [1 mark]
End correction is $49.8 - 48.9 = 0.9$ cm [1 mark]

ii) n = 1.97 so with end correction, n = 2 → **second harmonic**

21.

a. Any three from:
All collisions between particles are elastic / no energy loss
There are a large number of particles all moving at random velocities / at random speeds in random directions
The size of each particle is small / negligible compared to the size of the container / gas
The time during each particle collision is small / negligible compared to the time between collisions
[3 marks]

b. i) No heat change → increase in internal energy = work done on gas
Work done on gas = 4800 * 0.3 = 1440 J [1 mark]
Original internal energy = 3/2 * R * 298 = 3717 J [1 mark]
Total internal energy per molecule = 1440 + 3717 = 5157 J [1 mark]
5157 = ⅓ * (2.6×10^{-2}) * c^2 [1 mark]
c^2 = 484269 → r.m.s. = 696 = **700 ms^{-1}** (2 s.f.) [1 mark]

ii) work done = 101000 * (3 * 0.1 - 0.1) **= 20200 J** or **20000 J** [1 mark]

iii) pressure is **proportional to** temperature [1 mark]

iv) The curve for Process IV shows P being inversely proportional to V
or The product of the pressure and volume at any point is
3 P_0 V_0 = constant [1 mark]
So by Boyle's law the temperature is constant [1 mark]

22.

a. Conservation of energy: energy at top = energy at bottom

Let u = speed at bottom, v = speed at top, T = tension at top, g = 9.81

$(1/2 * 0.5 * u^2) = (1/2 * 0.5 * v^2) + (0.5 * g * 1)$ [1 mark]

$u^2 = v^2 + 2g$ [1 mark]

Force equation at the top:

$T + 0.5g = 0.5v^2/0.5$ [1 mark]

$T + 0.5g = v^2$ [1 mark]

Force equation at the bottom:

$5T - 0.5g = 0.5u^2/0.5$ [1 mark]

$5T - 0.5g = u^2$ [1 mark]

Sub into energy equation,

$5T - 0.5g = T + 0.5g + 2g$ [1 mark]

$4T = 3g$

$T = 3/4 * 9.81 =$ **7.36 N** [1 mark]

b. Deduces that the place most likely to go slack is at the top

Force equation at the top:

$0.5g + T = 0.5v^2/0.5$, T = 0 when slack → $0.5g = v^2$ [3 marks]

Using energy equation,

$u^2 = v^2 + 2g$ [3 marks: may rederive]

$u^2 = 0.5g + 2g = 2.5g$

$u = 4.95\ ms^{-1}$ [1 mark]