HODDER Education

Physics review
www.hoddereducation.com/physicsreview

Volume 33, Number 3, February 2024

Answers

Practice-for-exam questions

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Plasmas — the fourth state of matter

1 **a** Mass of an electron is 9.1 x 10^{-31} kg and speed of light c is 3.0 x 10^{8} ms^{-1}. Using Einstein's mass-energy formula:

$$E = mc^2$$

$$E_{electron} = 9.1 \times 10^{-31} \times (3.0 \times 10^8)^2 J$$

$$E_{electron} = \mathbf{8.19 \times 10^{-14}\ J}\ (3\ \text{s.f.})$$

b Using the mole mass (in kg) and Avogadro's number N (value provided in the question), the mass of 1 atom of hydrogen can be calculated as:

$$m_h = \frac{mole\ mass}{N} = \frac{1.01 \times 10^{-3} kg}{6.02 \times 10^{23}}$$

Using this in Einstein's formula we can find the energy equivalent of 1 atom of hydrogen:

$$E_{hydrogen\ atom} = \left(\frac{1.01 \times 10^{-3}}{6.02 \times 10^{23}}\right) \times (3.0 \times 10^8)^2 J$$

$$E_{hydrogen\ atom} = \mathbf{1.51 \times 10^{-10}\ J}\ (3\ \text{s.f.})$$

c The mass of a human weighing 150 N on the moon can be found by using Newton's second law of motion:

$$W_{human} = m_{human} \times g_{moon}$$

$$m_{human} = W_{human} \times \frac{1}{g_{moon}} = \frac{150}{1.63}\ \text{kg}$$

Like in part **b**:

$$E_{human} = \frac{150}{1.63} \times (3.0 \times 10^8)^2 J = \mathbf{8.28 \times 10^{18}\ J}\ (3\ \text{s.f.})$$

2 5.0 MeV in Joules is calculated as:

$$5.0\ MeV = 5.0 \times 10^6 \times 1.6 \times 10^{-19} \text{J} = 8.0 \times 10^{-13}\ \text{J}$$

The mass deficit is therefore:

$$m = \frac{E}{c^2} = \frac{8.0 \times 10^{-13} J}{(3.0 \times 10^8\ m\ s^{-1})^2} = 8.89 \times 10^{-30}\ kg$$

Energy in a kinetic store is given by:

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

Re-arranging for velocity:

$$v = \sqrt{\frac{2KE}{m}} = \sqrt{\frac{2 \times 8.0 \times 10^{-13}}{m}} \ldots eq(1)$$

There are 2 protons and 2 neutrons in the Helium nucleus, and thus m can be calculated as:

$$m = 2 \times m_{proton} + 2 \times m_{neutron} = 2 \times (1.67 \times 10^{-27}) + 2(1.67 \times 10^{-27})$$

$$m = 6.68 \times 10^{-27}\text{kg}$$

Substituting this value in equation (1), we get

$$v = \sqrt{\frac{2KE}{m}} = \sqrt{\frac{2 \times 8.0 \times 10^{-13} J}{6.68 \times 10^{-27} kg}} = \mathbf{1.55 \times 10^{7}\ ms^{-1}}\ (3\ \text{s.f.})$$

3 p-p IV branch reaction given by:

$${}^{3}_{2}He + {}^{1}_{1}H \rightarrow {}^{4}_{2}He + e^{+} + v_e$$

The energy of the products of the reaction is:

$$E_{product} = E({}^{4}_{2}He) + E(e^{+}) + E(v_e)$$

Each value on the right-hand side can be calculated by invoking Einstein mass-energy equation.

$$E({}^{4}_{2}He) = m_{({}^{4}_{2}He)} \times c^2 = (6.65 \times 10^{-27}) \times (3.00 \times 10^{8})^2 = 5.985 \times 10^{-10}\ \text{J}$$

$$E(e^{+}) = m_{(e^{+})} \times c^2 = (9.11 \times 10^{-31}) \times (3.00 \times 10^{8})^2 = 8.199 \times 10^{-14}\ \text{J}$$

$$E(v_e) = m_{(v_e)} \times c^2 = (0) \times (3.00 \times 10^{8})^2 = 0\ \text{J}$$

$$\therefore E_{product} = 5.985 \times 10^{-10} + 8.199 \times 10^{-14} + 0 = 5.9858199 \times 10^{-10}\ \text{J}$$

The energy of the reactants of the reaction is:

$$E_{reactants} = E({}^{3}_{2}He) + E({}^{1}_{1}He)$$

Each value on the right-hand side can be calculated by once again invoking Einstein's mass-energy equation, keeping all significant figures until the end of the calculation.

$$E({}^{3}_{2}He) = m_{({}^{3}_{2}He)} \times c^2 = (5.00 \times 10^{-27}) \times (3.00 \times 10^{8})^2 = 4.50 \times 10^{-10}\ \text{J}$$

$$E({}^{1}_{1}He) = m_{({}^{1}_{1}He)} \times c^2 = (1.67 \times 10^{-27}) \times (3.00 \times 10^{8})^2 = 1.503 \times 10^{-10}\ \text{J}$$

$$\therefore E_{reactants} = 4.5 \times 10^{-10} + 1.503 \times 10^{-10} = 6.003 \times 10^{-10}\ \text{J}$$

Energy released is given by, as explained in Box 3 of the article:

$$\text{E}_{\text{released}} = E_{reactants} - E_{product}$$

$$\text{E}_{\text{released}} = (6.003 \times 10^{-10}) - (5.9858199 \times 10^{-10})$$

$$\text{E}_{\text{released}} = 1.718 \times 10^{-12}\text{J}$$

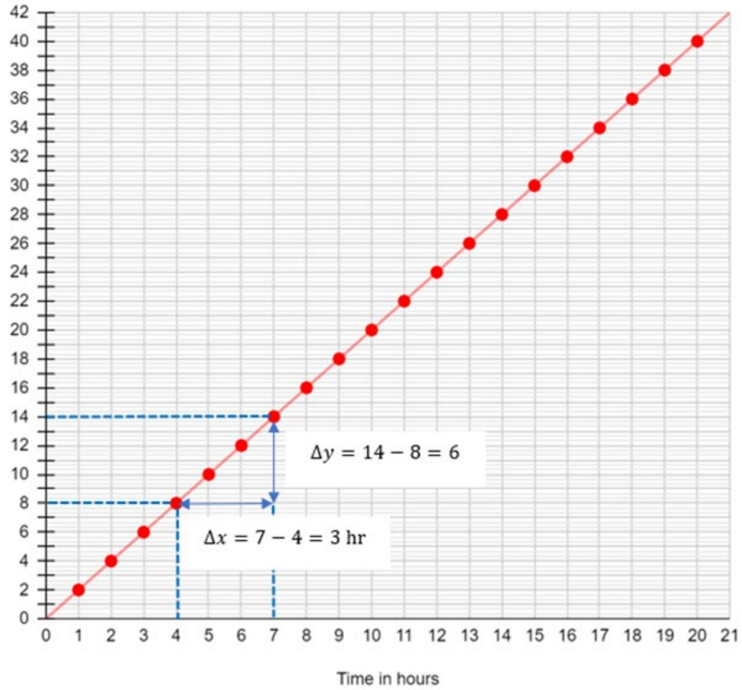
To convert into eV, divide the value by 1.6×10^{-19}

$$E_{released} = \frac{1.718 \times 10^{-12}}{1.6 \times 10^{-19}}\ eV = \mathbf{10.7\ MeV}\ (3\ s.f.)$$

Equations from graphs

1

Natural logarithm 'ln' (number of bacteria



Graph provided with markers for gradient calculations. 'ln' refers to logarithm to the base 'e' (also called the natural logarithm)

a Gradient calculation can be found by finding the change in Y-axis value as well as the change the x-axis value between any two points along the trend line (line of best fit has already been provided in the graph).

$$slope = m = \frac{\Delta y}{\Delta x} = \frac{6}{3} = 2\ h^{-1}$$

b The equation of a straight line is

$$y = m.x + c$$

For the line in question, the intercept c is 0 and slope has been calculated in part **a**. Substituting this, we get

$$y = 2\ x$$

Here y represents the logarithm to the base e of the number of bacteria N and x represents time in hours. We can now write

$$ln\ N = 2\ h^{-1} \times t_{hr}$$

where t_{hr} is the time in hours.

The constant of proportionality, 2 hr^{-1}, can be converted into a constant in terms of seconds as follows:

$$\frac{2}{1\ h} = \frac{2}{3600\ s} = \frac{1}{1800} s^{-1}$$

Therefore:

$$ln\, N = \frac{1}{1800} s^{-1} \times t_s$$

where t_s is the time in seconds.

Taking exponentials of both sides (the exponential function and the natural logarithm are inverse functions of one another) gives:

$$N = e^{\frac{1}{1800} s^{-1} \times t_{seconds}}$$

Using:

$$ln\, N = 2\, h^{-1}\, t_{hr}$$

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with $t_{hr} = 48\, h$ we get:

$$ln\, N = 2\, h^{-1} \times 48\, h = \mathbf{96}$$

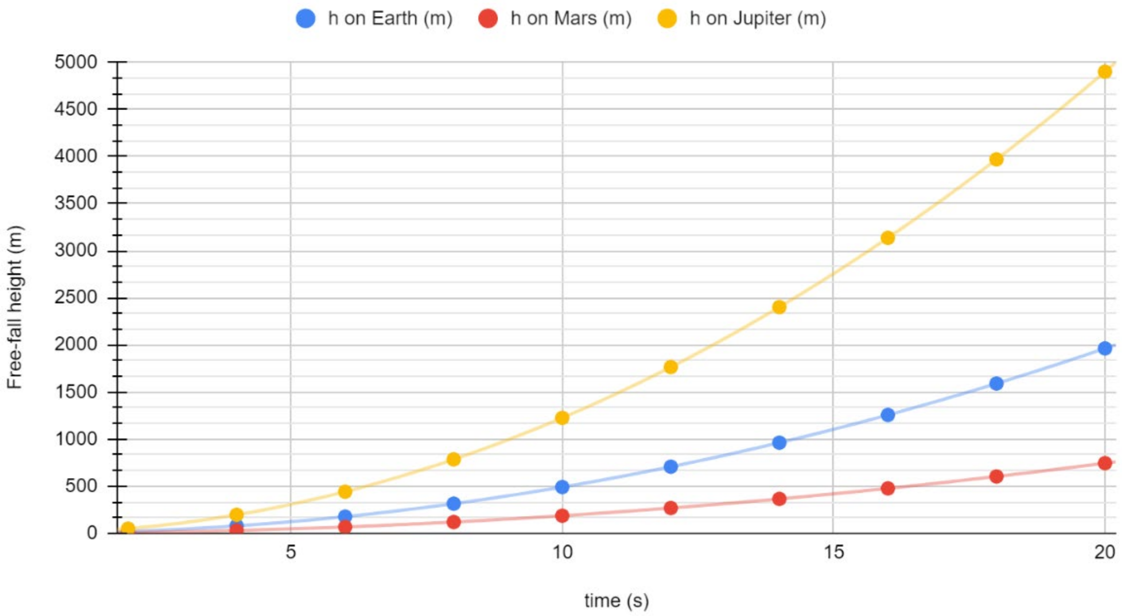
Hence:

$$N = e^{96} = 4.92 \times 10^{41}$$

2 **a** Completed Table 1 below. All values to 3 s.f.

Time *t* / *s*	*Free-fall height h / m*		
	on Earth	on Mars	on Jupiter
2.00	19.6	7.44	49
4.00	78.5	29.8	196
6.00	177	67.0	441
8.00	314	119	784
10.0	491	186	1.23×10^3
12.0	706	268	1.76×10^3
14.0	961	365	2.40×10^3
16.0	1.26×10^3	476	3.14×10^3
18.0	1.59×10^3	603	3.97×10^3
20.0	1.96×10^3	744	4.90×10^3

b Data from completed Table 1 above has been plotted in the graph below.



Graph for free-fall distances vs time on Earth, Mars and Jupiter

c Taking logs to base 10 on both sides of the given equation:

$$h = \frac{1}{2}gt^2$$

we get:

$$\log_{10} h = \log_{10}\left(\frac{1}{2}gt^2\right)$$

$$\log_{10} h = \log_{10}\left(\frac{1}{2}\right) + \log_{10} g + \log_{10} t^2$$

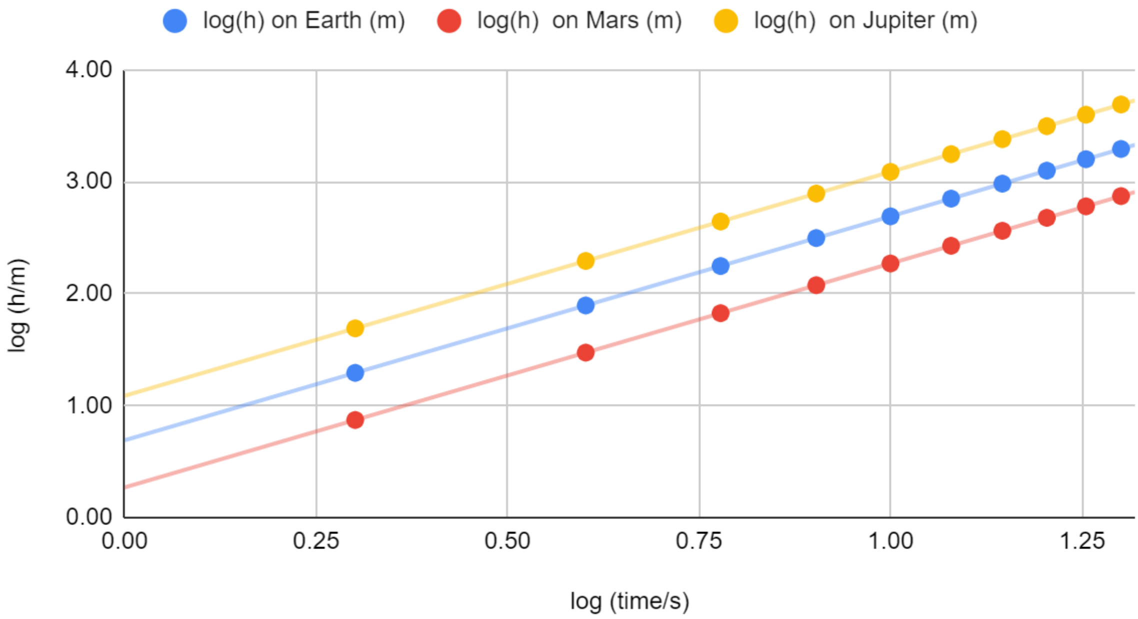
$$\log_{10} h = \log_{10}\left(\frac{1}{2}\right) + \log_{10} g + 2\log_{10} t$$

$$\mathbf{\log_{10} h = 2\log_{10} t + \log_{10} g - 0.30}$$

Completed Table 2 below (3 s.f.):

log(t/s)	log(h/m) on Earth	log(h/m) on Mars	log(h/m) on Jupiter
0.30	1.29	0.87	1.69
0.60	1.89	1.47	2.29
0.78	2.25	1.83	2.64
0.90	2.50	2.08	2.89
1.00	2.69	2.27	3.09
1.08	2.85	2.43	3.25
1.15	2.98	2.56	3.38
1.20	3.10	2.68	3.50
1.26	3.20	2.78	3.60
1.30	3.29	2.87	3.69

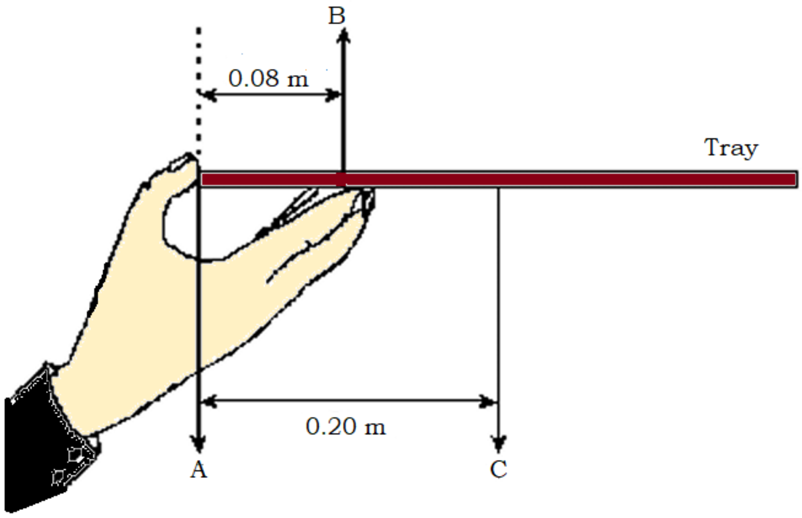
d The graph plotted below shows that each curve has the **same slope of 2** (notice how the lines are parallel to each other).



Log (h/m) vs log (t/s) for each planet

Moments, torque and electric cars

1 **a**



A person holding a tray (as shown in the question)

i First relationship: resultant force acting on tray is zero i.e. A+C = B [sum of downward forces = sum of upward forces]

Second relationship: resultant torque is zero.

ii Force C is the weight of the tray given by:

$C = m \times g$

$C = 0.20\, kg\ \times 9.81\, N\, kg^{-1}$

$C = \mathbf{1.96}\ \mathrm{N}\ (3\ \mathrm{s.f.})$

iii Taking moments about A gives:

$B \times 0.08\, m = C \times 0.20\, m$

Substituting value of C as determined in part **ii**:

$B\ \times 0.08\, m = 0.20\, kg\ \times 9.81\, N\, kg^{-1} \times 0.20\, m$

$B \times 0.08\, m = 0.3924\, N\, m$

$B = 4.905\, N = \mathbf{4.91\ N}\ (3\ \mathrm{s.f.})$

For resultant force to be zero:

$A + C = B$

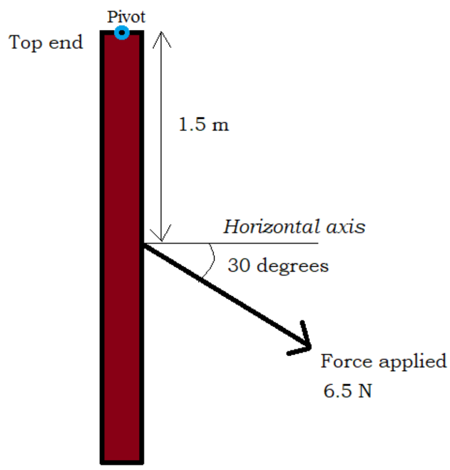
$A = B - (0.20\, kg \times 9.81\, m\, s^{-2})$

$A = 4.905\, N - (0.20\, kg \times 9.81\, N\, kg^{-1})$

$A = 2.943\, N = \mathbf{2.94\ N}\ (3\ \mathrm{s.f.})$

b The glass would need to be placed at B. No additional turning moment about B.

2



Rod with a force applied at an angle of 30 degrees to the horizontal at a point 1.5 m from its top end

The angle between the position vector of the point of application of the force from the pivot, and the force vectors is the complement of the angle marked in the diagram, i.e. 60 ^{o}. Therefore, using τ for the torque:

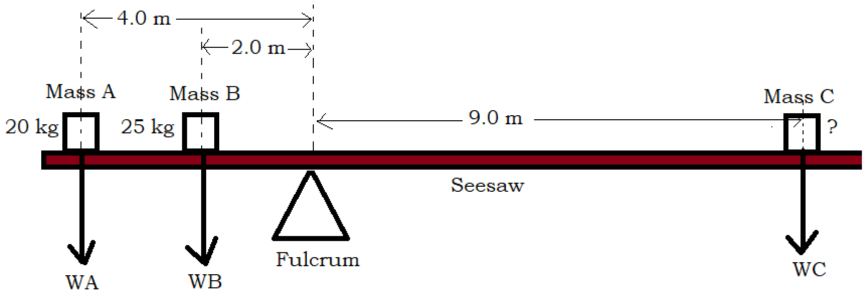
$\tau = F \times d \times \sin\theta$

Substituting the values given:

$\tau = 6.5\ N \times 1.5\ m \times \sin 60^o$

$\tau = 84.437\ N\ m = \mathbf{84\ N\ m}\ (2\ \text{s.f.})$

3



Representation of how the various masses are positioned on the seesaw

For the see-saw to balanced, clockwise and anti-clockwise moments must be equal. Because the constant of proportionality between the mass and the weights (g) is the same for all the masses, we can use the masses rather than the weights. That is to say:

$(Mass_A \times d_A) + (Mass_B \times d_B) = Mass_C \times d_C$

Substituting the values provided in the question:

$(20\ kg \times 4.0\ m) + (25kg \times 2.0\ m) = Mass_C \times 9.0\ m$

$(80 + 50)kg\ m = Mass_C \times 9.0\ m$

$$Mass_C = \frac{130\ kg\ m}{9.0\ m} = 14.44\ kg = \mathbf{14\ kg}\ (2\ \text{s.f.})$$

Domestic 'heat batteries'

1 Volume of water contained in the cylinder (when completely filled):

$V_{cylinder} = \pi \times r^2 \times h$

Where r is the radius and h the height of the cylinder.

Substituting the values provided:

$V_{cylinder} = \pi(10)^2(40)cm^3 = 12566.37\ cm^3$

As 1 cm = 10^{-2} m, the volume in m^3 is:

$V_{cylinder} = 12566.37\ \times (10^{-2})^3 m^3$

Flow rate is thus calculated as:

$$Flow\ rate = \frac{V_{cylinder}}{time\ taken} = \frac{12566.37 \times\ (10^{-2})^3 m^3}{3\ \times 60\ s} = 6.98 \times 10^{-5} m^3/s$$

1 m^3 = 1000 litres and so the flow rate in litres/s will be:

$Flow\ rate = 6.98\ \times 10^{-2} l/s$

a In **winter**, the water temperature needs to be raised by:

$$Temp\ change = Final\ temperature - Initial\ temperature = 40^oC - 8^oC = 32\ °C$$

To heat 1 litre of water (which is approximately 1 kg of water), energy required is:

$$Energy\ per\ litre = SHC\ \times Temp\ change$$

$$Energy\ per\ litre = 4.2\ \times 10^3 \times 32\ J\ l^{-1} = 134400\ J\ l^{-1}$$

Thus, the power required will be:

$$P_{winter} = Energy\ per\ litre\ \times Flow\ rate = \ 134400\ J\ l^{-1} \times 6.98 \times 10^{-2} l\ s^{-1}$$
$$= \mathbf{9.38\ kW}\ (3\ \mathrm{s.f.})$$

b In **summer**, the water temperature needs to be raised by:

$$Temp\ change = Final\ temperature - Initial\ temperature = 38^oC - 12^oC = 26\ °C$$

To heat 1 litre of water (which is approximately 1 kg of water), energy required is:

$$Energy\ per\ litre = SHC\ \times Temp\ change$$

$$Energy\ per\ litre = 4.2\ \times 10^3 \times 26\ J\ l^{-1} = 109200\ J\ l^{-1}$$

Thus, the power required will be:

$$P_{summer} = Energy\ per\ litre\ \times Flow\ rate = \ 109200\ \times 6.98 \times 10^{-2} kW$$
$$= \mathbf{7.62\ kW}\ (3\ \mathrm{s.f.})$$

2 **a** ‘Specific latent heat’ refers to the energy needed per kilogram of a pure substance to effect a change of state (melting or boiling) without changing its temperature. When a substance is warmed up or cooled down, one might assume the temperature rise or falls, but during change of state the temperature remains constant with the heat going in or heat coming out appearing to be ‘hidden’ within the substance – this is what the word ‘latent’ refers to. The word ‘specific’ simply refers to the amount of the substance. 1 kg is the amount most used.

b To boil away 50 g of water at 100 ° C, all of it must convert to steam.

$$Energy = mass\ \times latent\ heat\ of\ vaporisation$$
$$Energy = 0.050\ \times 2.26\ \times 10^6 J$$
$$Energy = \mathbf{113\ kJ}$$

c $Energy = mass\ \times latent\ heat\ of\ fusion$

$$mass = \frac{Energy}{latent\ heat\ of\ fusion}$$

$$mass = \frac{5200}{63000} kg = \mathbf{82.5\ g}\ (3\ \mathrm{s.f.})$$

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