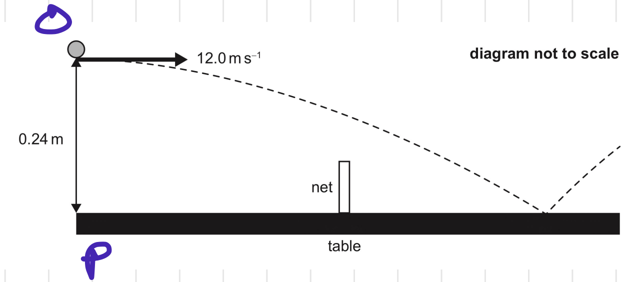
Physics Standard level Paper 2
Monday 3 May 2021 (afternoon)
1 hour 15 minutes

Answered with full explanation

IB PHYSICS SL PAPER-2 3 MAY-2021 SOLUTION

WITH EXPLANATION

1. Two players are playing table tennis. Player A hits the ball at a height of 0.24 m above the edge of the table, measured from the top of the table to the bottom of the ball. The initial speed of the ball is 12.0 m s-1 horizontally. Assume that air resistance is negligible.



Consider vertical motion between point O & P.

$$s = u(t) + \tfrac{1}{2}at^2$$

$$-0.24 = 0(t) - \tfrac{1}{2}(9.8 \times t^2)$$

$$t^2 = \frac{.24 \times 2}{9.8} \Rightarrow 0.2 \text{ sec} = t$$

(a) Show that the time taken for the ball to reach the surface of the table is about 0.2 s.

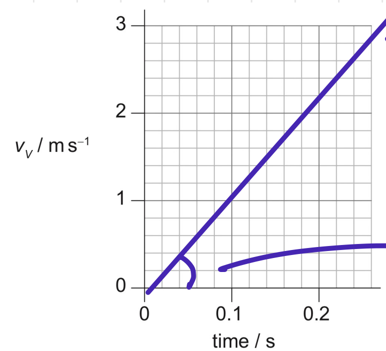
(b) Sketch, on the axes, a graph showing the variation with time of the vertical component of velocity v_y of the ball until it reaches the table surface. Take g to be +10ms-2. [2]

$$V_y = u_y + a_y t$$

$$-V_y = 0 - g t$$

$$V_y = g t$$

$$V_y = 10(t)$$

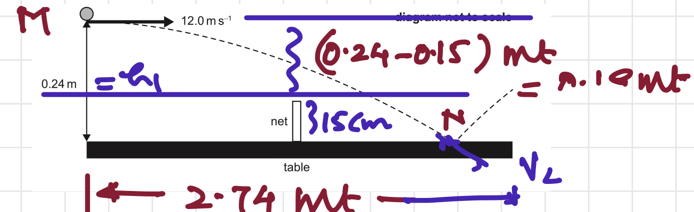


$V_y = 10(t)$

$\tan\theta = \frac{1}{0.1} = 10$

(Question 1 continued)

(c) The net is stretched across the middle and the net has a height of 15.0 cm. Show that the ball will go over the net of the table. The table has a length of 2.74 m.



Net – middle of the table

$$S_x = U_x t + \frac{1}{2} a_x t^2$$

$$\frac{2.74}{2} = (12)(t) \Rightarrow t = \frac{2.74}{24}$$

$$-S_y = 0 \times t - \frac{1}{2} \times 9.8 \times t^2$$

$$S_y = \frac{1}{2} \times 9.8 \times \frac{2.74 \times 2.74}{24 \times 24} = 6.38 \text{ mt}$$

$= .06$ mt

much over the height of the net.

(d) The ball bounces and then reaches a peak height of 0.18 m above the table with a horizontal speed of 10.5 m s-1. The mass of the ball is 2.7 g.

(i) Determine the kinetic energy of the ball immediately after the bounce.

Apply conservation of energy between point M & N

$$mgh + \frac{1}{2} m v_1^2 = 0 + \frac{1}{2} m v_2^2$$

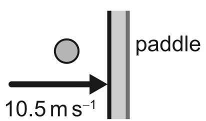
$$\frac{2.7}{1000} \times 10 \times .24 + \frac{1}{2} \frac{2.7}{1000} (12)^2 = \frac{1}{2} m v_2^2$$

$$.00648 + 1.944 = \frac{1}{2} m v_2^2$$

$$1.955 = \frac{1}{2} m v_2^2$$

ANS d (i)

(ii) Player B intercepts the ball when it is at its peak height. Player B holds a paddle (racket) stationary and vertical. The ball is in contact with the paddle for 0.010 s. Assume the collision is elastic.



Calculate the average force exerted by the ball on the paddle. State your answer
to an appropriate number of significant figures. [3]

$$F \cdot \Delta t = m(\Delta v) = m(v_f - v_i)$$

$$F = \frac{2.7}{1000} \frac{(10.5 - (-10.5))}{.010} = \frac{2.7 \times 2 \times 10.5}{1000 \times .010}$$

$$= 5.67 \text{ N} \simeq 5.7 \text{ N}$$

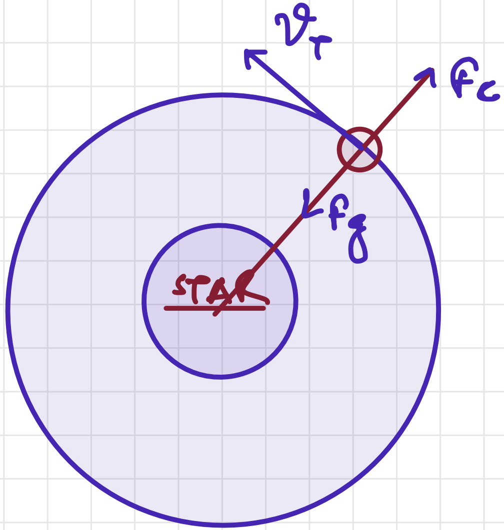
2. A planet is in a circular orbit around a star. The speed of the planet is constant. The following
data are given:
Mass of planet = 8.0×10^{24} kg Mass of star = 3.2×10^{30} kg Distance from the star to the planet R = 4.4×10^{10} mt

(a) Explain why a centripetal force is needed for the planet to be in a circular orbit.

ANS 2 (a)

for circular motion

$$\frac{G M_s m_p}{r^2} = \frac{m v^2}{r} \text{ (at the centre)}$$



→ circular motion involves change in velocity

→ centripetal acceleration is perpendicular to the tangential velocity.

(b) Calculate the value of the centripetal force

$$F = \frac{G m_1 m_2}{r^2}$$

$$= \frac{6.67 \times 10^{-11} \times 8.0 \times 10^{24} \times 3.2 \times 10^{30}}{(4.4 \times 10^{10})^2}$$

$$= \frac{6.67 \times 8.0 \times 3.2 \times 10^{-11+24+30}}{4.4 \times 4.4 \times 10^{20}}$$

$$= \left(\frac{6.67 \times 8.0 \times 3.2}{4.4 \times 4.4}\right) \times 10^{-11+24+30-20}$$

$$= 8.81 \times 10^{23} \text{ Newton}$$

(c) A spacecraft is to be launched from the surface of the planet to escape from the star system.The radius of the planet is 9.1×10^3 km

(i) Show that the gravitational potential due to the planet and the star at the surface of the planet is about -5×10^9 J kg-1.

Potential $V_p = -\frac{GM_p}{r_p} = -\frac{6.67 \times 10^{-34} \times 8.0 \times 10^{24}}{9.1 \times 10^3 \times 10^3} = -5.8 \times 10^7$ J/kg

$V_s = -\frac{GM_s}{r_s} = -\frac{6.67 \times 10^{-34} \times 3.2 \times 10^{30}}{4.4 \times 10^{10}} = -4.85 \times 10^9$ J/kg

Total potential $\Rightarrow V = V_p + V_s = -5 \times 10^9$ J/kg

(ii) Estimate the escape speed of the spacecraft from the planet-star system.

$E_{TOTAL} > 0, \quad E_K > |E_p| = mV_g$

$\frac{\cancel{m}v^2}{2} > \cancel{m}V_g$

$v^2 > 2V_g > 2 \times 4.9 \times 10^9$

$v > \sqrt{2 \times 4.9 \times 10^9} = 9.91 \times 10^4 \text{ m s}^{-1}$

3. A mass of 1.0 kg of water is brought to its boiling point of 100 °C using an electric heater of power 1.6kW.
(a) (i) The molar mass of water is 18 g mol-1. Estimate the average speed of the water molecules in the vapor produced. Assume the vapor behaves as an ideal gas

$$\frac{3}{\cancel{2}} KT = \frac{1}{\cancel{2}} m v^2 \Rightarrow v = \sqrt{\frac{3KT}{m}}$$

$$= \sqrt{\frac{3KT(N_a)}{\mu}}$$

$$\text{mass} = \frac{\mu}{N_a}$$

$$= \sqrt{\frac{3 \times 1.38 \times \cancel{10^{-23}} \times (373) \times 6.02 \times \cancel{10^{23}}}{18 \times 10^{-3}}}$$

$$= \sqrt{\frac{3 \times 1.38 \times 373 \times 6.02}{18 \times 10^{-3}}} \simeq 720 \text{ m s}^{-1}$$

(ii) State one assumption of the kinetic model of an ideal gas.

— particle can be considered points. (without dimension)
— No intermolecular forces
— Volume of the particle is negligible to the volume of the gas

(b) A mass of 0.86 kg of water remains after it has boiled for 200 s.
(i) Estimate the specific latent heat of vaporization of water. State an appropriate unit for your answer.

→ water vaporised $= 1 - 0.86$
$= 0.14\,kg$.

$$P = \frac{W}{t} \Rightarrow W = P(t) \Rightarrow m.L = 1.6 \times 10^3 \times 200$$

$$L = \frac{1.6 \times 10^3 \times 200}{0.14} = 2.3 \times 10^6\ J/kg.$$

(ii) Explain why the temperature of water remains at 100 °C during this time

All the energy added to use to break the bond.

(c) The heater is removed and a mass of 0.30 kg of pasta at -10 °C is added to the boiling water. Determine the equilibrium temperature of the pasta and water after the pasta is added. Other heat transfers are negligible.

Specific heat capacity of pasta = 1.8 kJ kg-1 K-1 Specific heat capacity of water = 4.2 kJ kg-1 K-1

Heat lost by the water = Heat gaind by the pasta

$$m_{water} S_{water} (100 - T) = m_{pasta} S_{pasta} (T - (-10))$$

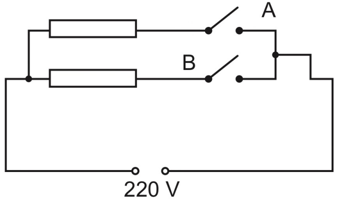
$$0.86 \times 4.2 \times (100 - T) = 0.30 \times 1.8 \times (T + 10)$$

$$3.612 \times 100 - 3.612 T = 0.54 T + 0.54 \times 10$$

$$361.2 - 5.4 = (3.612 + 0.54) T$$

$$T = \frac{355.8}{4.152} \simeq \underline{86^\circ C}$$

(d) The electric heater has two identical resistors connected in parallel.



The circuit transfers 1.6 kW when switch A only is closed. The external voltage is 220 V.

(i) Show that each resistor has a resistance of about 30 Ω.

$$P = \frac{V^2}{R} = 1.6\times10^3\,W$$

$$1.6\times10^3 = \frac{(220)^2}{R}$$

$$R = \frac{220\times220}{1.6\times10^3} = \frac{\cancel{22}^{11}\times\cancel{22}^{11}}{\cancel{16}\,\cancel{8}\,4}$$

$$= \frac{121}{4} \simeq 30\text{-ohm}$$

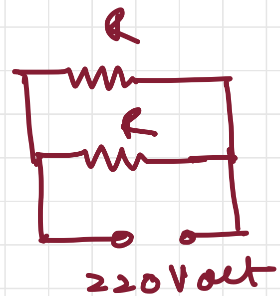
(ii) Calculate the power transferred by the heater when both switches are closed.

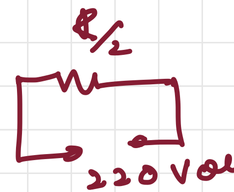
$$P' = \frac{V^2}{(R/2)} = 2\left(\frac{V^2}{R}\right)$$

$$= 2\times1.6\times10^3\,W$$

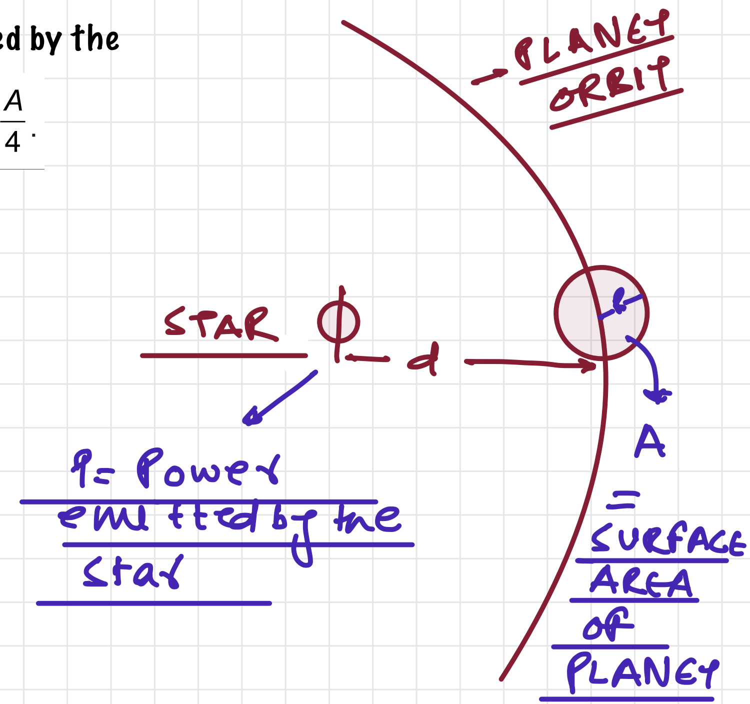
$$= 3.2\times10^3\,W = 3.2\,kW$$

$$= 3200\ \text{watt}$$





4. A planet orbits at a distance d from a star. The power emitted by the star is P. The total surface area of the planet is A.
(a) (i) Explain why the power incident on the planet is $\frac{P}{4\pi d^2} \times \frac{A}{4}$.



Surface Area of planet

$$A = 4\pi R^2$$

$$\frac{A}{4} = \pi R^2$$

Power radiated by the star on unit area at distance d is $= \frac{P}{4\pi d^2}$

Power incident on the planet $= \left(\frac{P}{4\pi d^2}\right)\left(\frac{A}{4}\right)$

(ii) The albedo of the planet is αp . The equilibrium surface temperature of the planet is T. Derive the expression

$$T = \sqrt[4]{\frac{P(1-\alpha_p)}{16\pi d^2 e\sigma}}$$

where e is the emissivity of the planet.

$$P_{emitted} = e\sigma A T^4$$

$$\text{albedo} = \frac{\text{Total scattered power}}{\text{total incident power}} = \alpha_p$$

from previous part

$$\left(\frac{P}{4\pi d^2}\right)\left(\frac{A}{4}\right)$$

$$P_{scattered} = (\alpha_p)(P_{incident})$$

$$P_{incident} = P_{scattered} + P_{emitted}$$

$$P_{incident} = \alpha_p P_{incident} + e\sigma A T^4$$

$$P_{incident}(1-\alpha_p) = e\sigma A T^4.$$

$$T^4 = \frac{P_{incident}(1-\alpha_p)}{e\sigma A}$$

$$T = \sqrt[4]{\frac{PA}{16\pi d^2}\frac{(1-\alpha_p)}{e\sigma A.}}$$

Proved

(b) On average, the Moon is the same distance from the Sun as the Earth. The Moon can be assumed to have an emissivity $e = 1$ and an albedo $\alpha M = 0.13$. The solar constant is 1.36×10^{3} W m-2. Calculate the surface temperature of the Moon.

$$P = \sqrt[4]{\frac{P}{4\pi d^2} \times \frac{(1-\alpha_p)}{4e\sigma}}$$

$$= \sqrt[4]{\frac{1.36 \times 10^3 \times (0.87)}{4 \times 5.67 \times 10^{-8}}}$$

$$T = 268.75 \text{ K}$$

$$T = 270 \text{ K}$$

5 Radioactive uranium-238 $\left({}^{238}_{92}U\right)$ produces a series of decays ending with a stable nuclide of lead. The nuclides in the series decay by either alpha (α) or beta-minus (β^-) processes.

(a) Uranium-238 decays into a nuclide of thorium-234 (Th).

Write down the complete equation for this radioactive decay.

$${}_{92}U^{238} \longrightarrow {}_{90}Th^{234} + {}_{2}He^{4}$$

(b) Thallium-206 $\left({}^{206}_{81}Tl\right)$ decays into lead-206 $\left({}^{206}_{82}Pb\right)$.

Identify the quark changes for this decay.

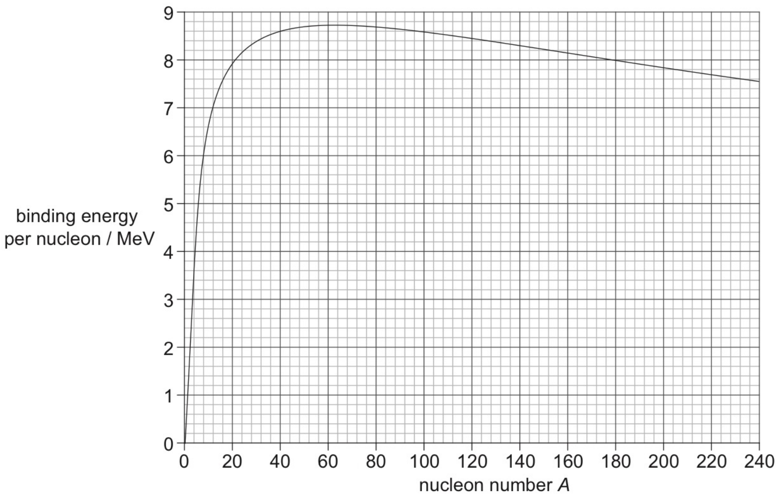
$${}_{81}Tl^{206} \longrightarrow {}_{82}Pb^{20} + {}_{-1}\beta^{0}$$

(c) The half-life of uranium-238 is about 4.5×10^9 years. The half-life of thallium-206 is about 4.2 minutes.

Compare and contrast the methods to measure these half-lives.

↳ measure Radioactive decay for either.

(d) The graph shows the variation with the nucleon number *A* of the binding energy per nucleon.



(i) Outline why high temperatures are required for fusion to occur. [2]

High temp = more KE, more speed

↳ energy required to overcome electrostatic repulsion

(ii) Outline, with reference to the graph, why energy is released both in fusion and in fission.

energy is released when binding energy per nucleon increases.

(iii) Uranium-235 ($^{235}_{92}U$) is used as a nuclear fuel. The fission of uranium-235 can produce krypton-89 and barium-144.

Determine, in MeV and using the graph, the energy released by this fission.

$$_{92}U^{235} \longrightarrow Kr^{89} + Ba^{144} + Q.$$

$U^{235} \downarrow 235 \times 7.6$ MeV

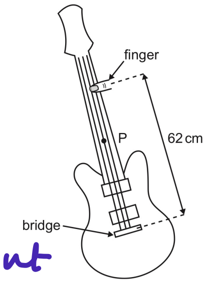
$Kr^{89} \downarrow 89 \times 8.6$ MeV

$Ba^{144} \downarrow 144 \times 8.2$ MeV

$$Q = [(235)(7.6) - (89)(8.6) - (144 \times 8.2)]$$

$$= 160 \text{ MeV}$$

6. On a guitar, the strings played vibrate between two fixed points. The frequency of vibration is modified by changing the string length using a finger. The different strings have different wave speeds. When a string is plucked, a standing wave forms between the bridge and the finger.



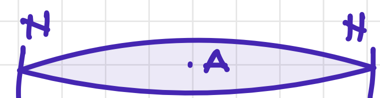
(a) Outline how a standing wave is produced on the string. [2]

Travelling wave moves along the length of the string and reflects at fixed end

And because of the superposition of incident and reflected wave, the standing wave is produced.

b) The string is displaced 0.4 cm at point P to sound the guitar. Point P on the string vibrates with simple harmonic motion (shm) in its first harmonic with a frequency of 195 Hz. The sounding length of the string is 62 cm.

(i) Show that the speed of the wave on the string is about 240 m s-1.



Amplitude = 0.4 cm , $f_1 = 195\ Hz$, $L = 0.62\ mt$ ← L → $= \lambda/2$

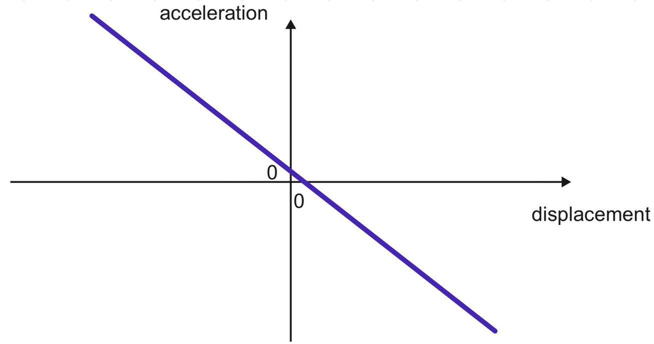
$$L = \frac{\lambda}{2} \Rightarrow \lambda = 2(L) = 2(0.62) = 1.24\ mt$$

$$v = f\lambda = (195)(1.24) = 242\ m/sec$$

(ii) Sketch a graph to show how the acceleration of point P varies with its displacement from the rest position.

For SHM

$A \propto -x$



7. Conservation of energy and conservation of momentum are two examples of conservation laws.

(a) Outline the significance of conservation laws for physics.

→ Both express principles of nature

→ $F_{ext} = \frac{dp}{dt}$, If $F_{external} = 0$, $p =$ constant

→ $(TE) = (KE) + (PE) =$ constant, can apply to two variable position and find out unknown quantity.

(b) When a pi meson π^- $(d\bar{u})$ and a proton (uud) collide, a possible outcome is a sigma baryon Σ^0 (uds) and a kaon meson K^0 $(d\bar{s})$.

Apply three conservation laws to show that this interaction is possible.

$d\bar{u} + uud \rightarrow uds + d\bar{s}$

Using idea that particle and antiparticle has opposite number.

$2d + \bar{u} + u + u \rightarrow 2d + u + s + \bar{s} \Rightarrow u = u$

Conservation: charge (Yes) $0 = 0$

baryon number Yes $\frac{1}{3} = \frac{1}{3}$

strangeness → Yes $0 = 0$