Physics Higher level Paper 2 Monday 3 May 2021 (afternoon) 2 hours 15 minutes

All questions with full explanation

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IB PHYSICS HL PAPER-2 3 MAY-2021 SOLUTION WITH EXPLANATION

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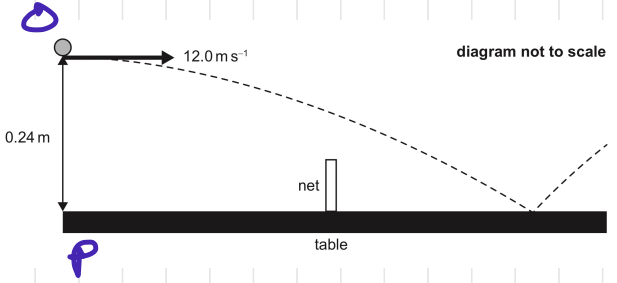
1. Two players are playing table tennis. Player A hits the ball at a height of 0.24 m above the edge of the table, measured from the top of the table to the bottom of the ball. The initial speed of the ball is 12.0 m s-1 horizontally. Assume that air resistance is negligible.



Consider vertical motion between point O & P.

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

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

$t^2 = \frac{0.24 \times 2}{9.8} \Rightarrow 0.2 \text{ sec} = t$

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

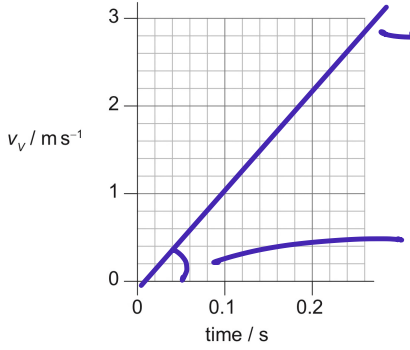
(b) Sketch, on the axes, a graph showing the variation with time of the vertical component of velocity v_y of the ball until it reaches the table surface. Take g to be +10 ms-2. [2]

$v_y = u_y + a_y t$

$-v_y = 0 - gt$

$v_y = gt$

$v_y = 10(t)$



$v_y = 10(t)$

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

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(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.

$s_x = u_x t + \frac{1}{2} a_x t^2$

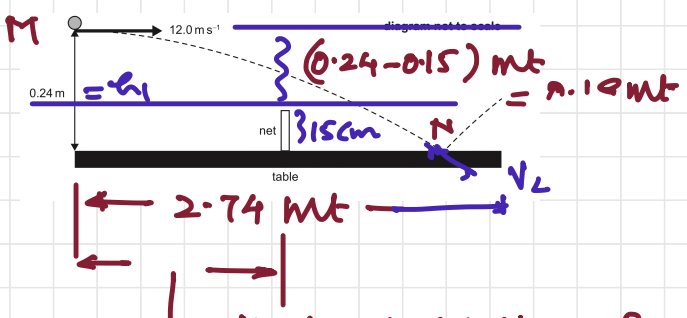
$\frac{2.74}{2} = (12)(t) \Rightarrow t = \frac{2.74}{24}$

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

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

$= .06\ \text{mt}$

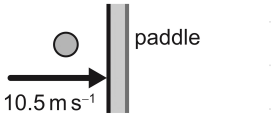
↳ much over the height of the net.



(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.

(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]

Apply conservation of energy between point M & N

$mgh + \frac{1}{2} m v_1^2 = 0 + \frac{1}{2} m V_2^2$

$\frac{2.7}{1000} \times 10 \times .24 + \frac{1}{2} \frac{2.7}{1000} (12)^2 = \frac{1}{2} m V_2^2$

$.006480 + 1.944 = \frac{1}{2} m v_2^2$

$1.955 = \frac{1}{2} m v_2^2$ — Ans d (i)

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

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

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

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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.

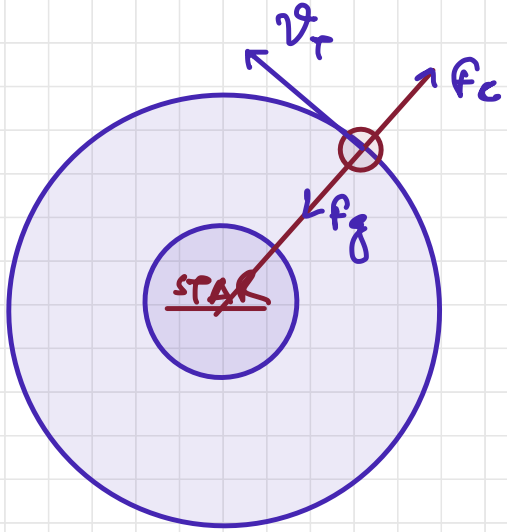
ANS 2 (a)

for circular motion

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

→ circular motion involves change in velocity

→ centripetal acceleration is perpendicular to the tangential velocity.



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(b) Calculate the value of the centripetal force

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

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

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

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

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

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(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.

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

$\frac{mV^2}{2} > mV_g$

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

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

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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

$$\frac{3}{2}kT = \frac{1}{2}m\vartheta^2 \Rightarrow \vartheta = \sqrt{\frac{3kT}{m}}$$

$$= \sqrt{\frac{3kT(N_a)}{M}} \qquad \text{mass} = \frac{M}{N_a}$$

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

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

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(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 us to break the bond.

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(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 gained by the pasta

$m_{water}\, s_{water}\, (100-T) = m_{pasta}\, s_{pasta}\, (T-(-10))$

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

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

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

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

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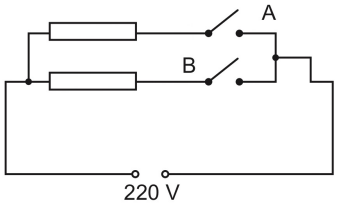
(d) The electric heater has two identical resistors connected in parallel.



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.

$P = \frac{V^2}{R} = 1.6 \times 10^3 W$

$1.6 \times 10^3 = \frac{(220)^2}{R}$

$R = \frac{220 \times 220}{1.6 \times 10^3} = \frac{11}{4}$

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

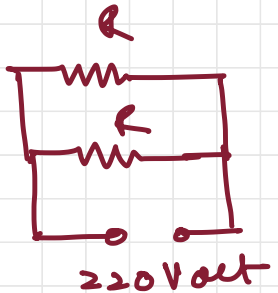
(ii) Calculate the power transferred by the heater when both switches are closed.

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

$= 2 \times 1.6 \times 10^3 W$

$= 3.2 \times 10^3 W = 3.2 kW$

$= 3200$ watt



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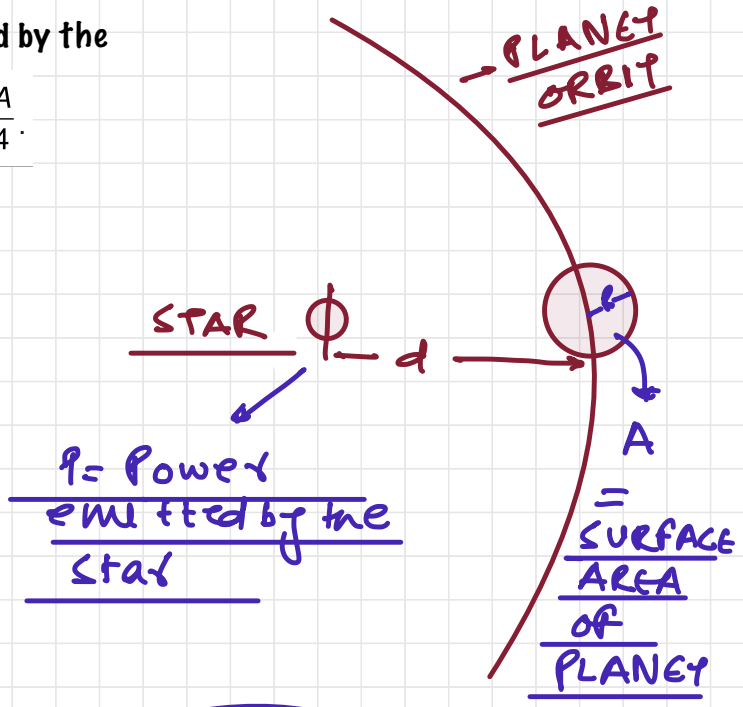
4. A planet orbits at a distance d from a star. The power emitted by the star is P. The total surface area of the planet is A.
(a) (i) Explain why the power incident on the planet is $\frac{P}{4\pi d^2} \times \frac{A}{4}$.

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 $= \frac{P}{4\pi d^2}$



P = Power emitted by the star

A = SURFACE AREA OF PLANET

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

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

(ii) The albedo of the planet is α_p. 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.

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

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

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

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

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

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

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

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

Proved

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(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 αM = 0.13. The solar constant is 1.36 x 10^3 W m-2. Calculate the surface temperature of the Moon.

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

$$= \sqrt[4]{\frac{1.36\times10^3 \times (0.87)}{4\times5.67\times10^{-8}}}$$

$$T = 268.75\ k$$

$$T = 270\ k$$

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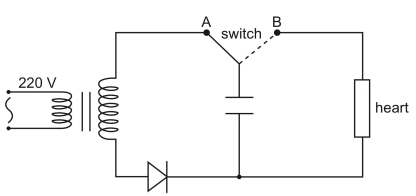
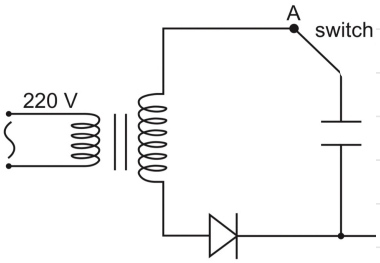
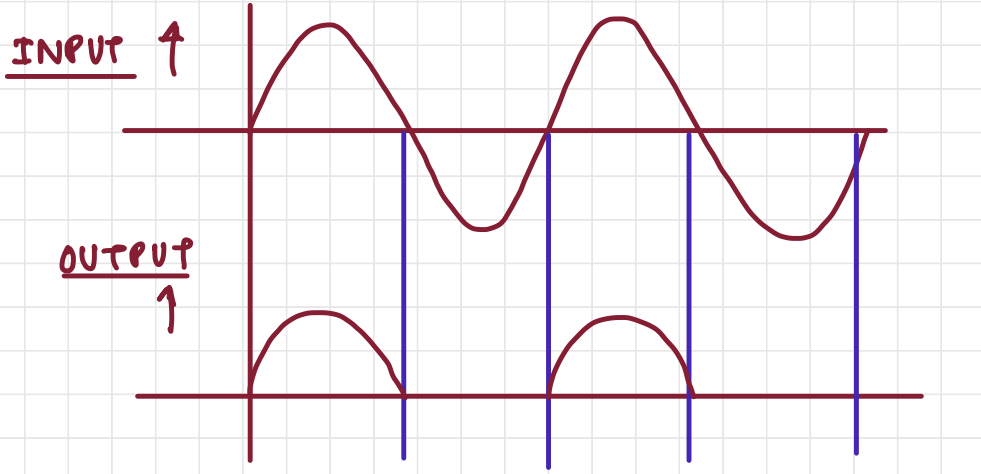
5. A device sends an impulse of electrical energy to maintain a regular heartbeat in a person. The device is powered by an alternating current (ac) supply connected to a step-up transformer that charges a capacitor of capacitance 30μF.



(a) Explain the role of the diode in the circuit when the switch is at position A. [2]





DIODE WILL ACT AS A HALF-WAVE RECTIFIER

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(b)
The voltage across the primary coil of the transformer is 220 V. The number of turns on the secondary coil is 15 times greater than the number of turns on the primary coil.

(i) Show that the maximum energy stored by the capacitor is about 160 J.

$V_1 = 220$ Volt

$N_1 = N$

$N_2 = 15N$

$\frac{N_2}{N_1} = \frac{V_2}{V_1}$

$\frac{15N}{N} = \frac{V_2}{220}$

$V_2 = (15)(220)$ Volt

$C = 30\mu F$

$U = \frac{1}{2} C V^2$

$= \frac{1}{2} (30 \times 10^{-6}) (15 \times 220)^2$

$= 163.35$ J

$\simeq 160$ J

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II)Calculate the maximum charge Q_0 stored in the capacitor.

$$Q_0 = CV = 30\times10^{-6} \times 3300 = .099C$$

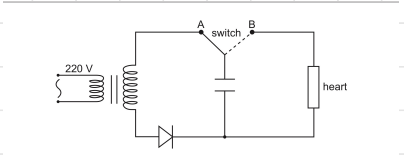
III) Identify, using the label + on the diagram, the polarity of the capacitor.

Lower plate is positive

(c) The switch is moved to position B.

i) Describe what happens to the energy stored in the capacitor when the switch is moved to position B.

the energy stored in the capacitor transferred to the load (heart)



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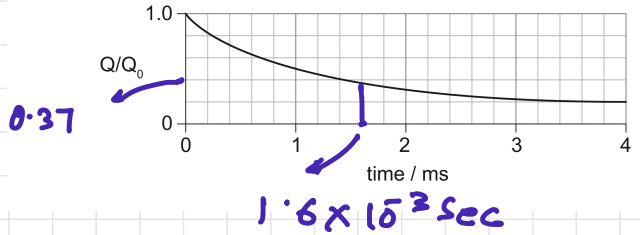
(ii) Show that the charge remaining in the capacitor after a time equal to one time constant τ of the circuit will be $0.37\ Q_0$

$$Q = Q_0 e^{-t/\tau} \qquad t = \tau$$

$$Q = Q_0 e^{-\tau/\tau} = Q_0/e = 0.368\ Q_0 = 0.37\ Q_0$$

(iii) The graph shows the variation with time of the charge in the capacitor as it is being discharged through the heart.



Determine the electrical resistance of the closed circuit with the switch in position B.

$$\tau = RC \Rightarrow R = \frac{\tau}{C} = \frac{1.6 \times 10^{-3}}{30 \times 10^{-6}}$$

$$= 53\text{-ohm}$$

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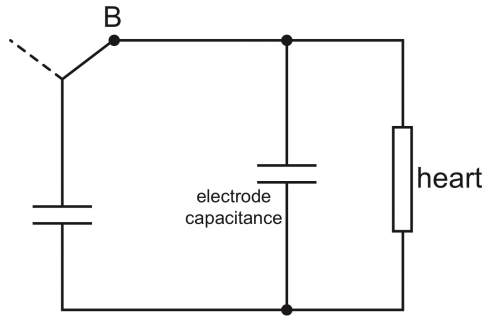
(d) In practice, two electrodes connect the heart to the circuit. These electrodes introduce an additional capacitance.



⇒ electrode makes a capacitor and true capacitor is connected parallel to the previous capacitor.

hence total capacitor increases

Explain the effect of the electrode capacitance on the discharge time.

therefore

$\tau = RC$ increases

hence discharging time increases.

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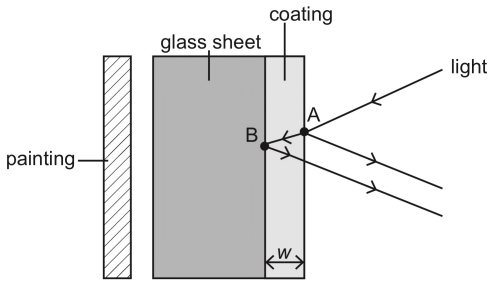
6. A painting is protected behind a transparent glass sheet of refractive index nglass. A coating of thickness w is added to the glass sheet to reduce reflection. The refractive index of the coating ncoating is such that nglass > ncoating > 1.

The diagram illustrates rays normally incident on the coating. Incident angles on the diagram are drawn away from the normal for clarity.



a) State the phase change when a ray is reflected at B.

Phase change at the denser medium = 180° (boundry)

B) Explain the condition for w that eliminates reflection for a particular light wavelength in air λair.

$(m+\frac{1}{2})\lambda_{coating} = 2w$ (path difference)

$\mu = \frac{\lambda_{air}}{\lambda_{coating}}$

$\lambda_{coating} = \frac{\lambda_{air}}{\mu}$

$w = (m+\frac{1}{2})\frac{\lambda}{2} = (m+\frac{1}{2})\frac{\lambda_{air}}{2\mu_{coating}}$

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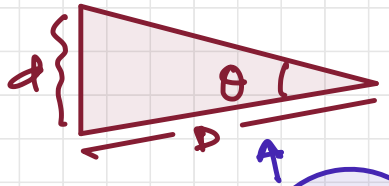
(6) (i) State the Rayleigh criterion for resolution

↳ central maxima of one diffraction pattern lies over the central/first minima of other diffraction pattern.

(c) (ii) The painting contains a pattern of red dots with a spacing of 3 mm. Assume the wavelength of red light is 700 nm. The average diameter of the pupil of a human eye is 4 mm. Calculate the maximum possible distance at which these red dots are distinguished.

$$\theta = \frac{1.22\lambda}{b}$$

for circular aperture



$$\theta = \frac{1.22 \times 700 \times 10^{-9}}{4 \times 10^{-3}} = 2.14 \times 10^{-4} \text{ radian}$$

$\theta = \frac{d}{D}$

$$D = \frac{d}{\theta} = \frac{3 \times 10^{-3}}{2.14 \times 10^{-4}} = 14 \text{ mt}$$

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7. Radioactive uranium-238 ($^{238}_{92}U$) 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 ($^{206}_{81}Tl$) decays into lead-206 ($^{206}_{82}Pb$).

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.

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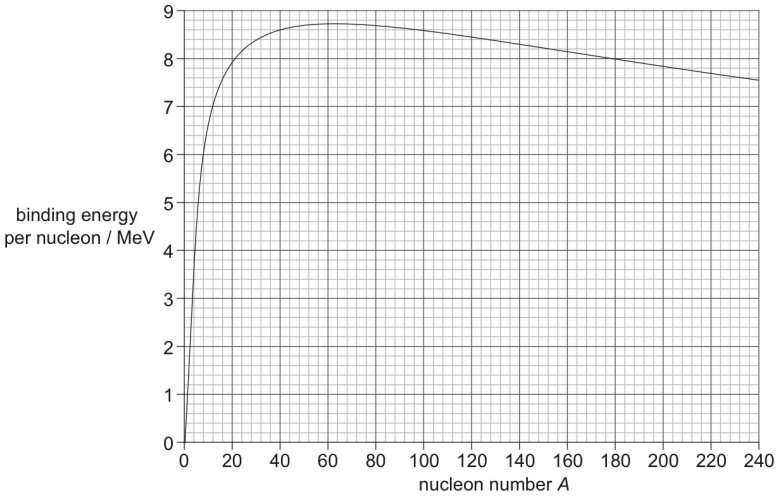
(d) The graph shows the variation with the nucleon number A of the binding energy per nucleon.



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

High temp = more KE, more speed

↳ energy required to overcome electrostatic repulsion

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(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 $\left({}^{235}_{92}\mathrm{U}\right)$ 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.

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

235×7.6 MeV

89×8.6 MeV $\quad 144 \times 8.2$ MeV

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

$$= 160 \text{ MeV}$$

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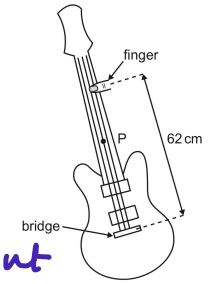
8. On a guitar, the strings played vibrate between two fixed points. The frequency of vibration is modified by changing the string length using a finger. The different strings have different wave speeds. When a string is plucked, a standing wave forms between the bridge and the finger.

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

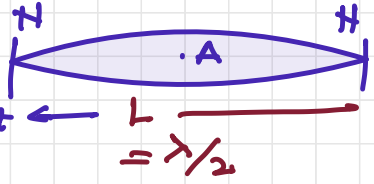


Travelling wave moves along the length of the string and reflects at fixed end

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

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

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

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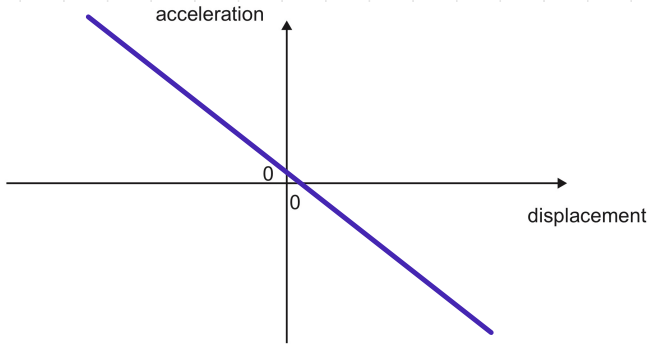
(ii) Sketch a graph to show how the acceleration of point P varies with its displacement from the rest position.

For SHM

$A \propto -x$



(iii) Calculate, in m s-1, the maximum velocity of vibration of point P when it is vibrating with a frequency of 195Hz.

$v = a\omega \cos \omega t$

$v_{max} = a\omega = a(2\pi f)$

$= 1.004 \times 2 \times 3.14 \times 195$

$= 4.9 \text{ m s}^{-1}$

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(iv) Calculate, in terms of g, the maximum acceleration of P.

$$\text{Max Acceleration} = -\omega^2 x = -(2\pi f)^2 (x_0)$$

$$= -(2\pi \times 195)^2 \times (.004)$$

$$= 6004\ m\bar{s}^2 = \frac{6000}{10} g$$

$$= 600\ g$$

(v) Estimate the displacement needed to double the energy of the string.

$$E = \frac{1}{2} m \omega^2 x^2$$

$$E \propto x^2 \quad , \quad x \propto \sqrt{E}$$

$$\frac{x}{x'} = \sqrt{\frac{E}{2E}} \Rightarrow x' = \sqrt{2}\, x$$

$$= \sqrt{2} \times (0.4\ cm)$$

$$= 0.6\ cm$$

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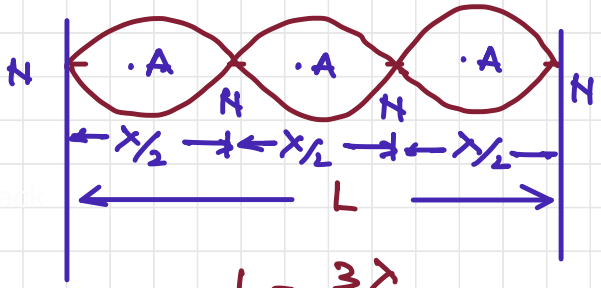
(c) The string is made to vibrate in its third harmonic. State the distance between consecutive nodes.



$$L = \frac{3\lambda}{2}$$

$$\frac{\lambda}{2} = \frac{L}{3} = \frac{62\,cm}{3}$$

$$= 21\,cm.$$

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9. 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 = conserved

→ (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 $0 = 0$

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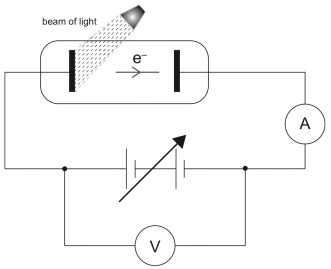
10. In an electric circuit used to investigate the photoelectric effect, the voltage is varied until the reading in the ammeter is zero. The stopping voltage that produces this reading is 1.40 V.



a) Describe the photoelectric effect.

The photoelectric effect is a phenomenon in which electrons are ejected from the surface of a metal when light is incident on it. These ejected electrons are called photoelectrons. It is important to note that the emission of photoelectrons and the kinetic energy of the ejected photoelectrons is dependent on the frequency of the light that is incident on the metal's surface. The process through which photoelectrons are ejected from the surface of the metal due to the action of light is commonly referred to as photoemission.

b) Show that the maximum velocity of the photoelectrons is 700kms-1.

$$eV_0 = \frac{1}{2} m v_{max}^2$$

$$v_{max} = \sqrt{\frac{2eV_0}{m}} = \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times 1.40}{9.1 \times 10^{-31}}}$$

$$= 700 \text{ km/sec}$$

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(c) The photoelectrons are emitted from a sodium surface. Sodium has a work function of 2.3 eV.

Calculate the wavelength of the radiation incident on the sodium. State an appropriate unit for your answer. [3

$$E = W_0 + eV_0$$

$$\frac{hc}{\lambda} = W_0 + eV_0$$

$$\frac{hc}{\lambda} = 2.3\,eV + 1.40\,eV = 3.70\,eV$$

$$\lambda = \frac{3.70 \times 1.6 \times 10^{-19}}{6.6 \times 10^{-34} \times 3 \times 10^{8}}$$

$$= 3.4 \times 10^{-7}\ m$$

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