2020 Raffles Institution Preliminary Examinations – H2 Physics

Paper 2 – Suggested Solutions

1 **(a)** The projectile undergoes a trajectory symmetrical about the centre (or parabolic trajectory), with vertical displacement $s_y = 0$.

Taking upwards as positive and considering vertical motion,

$$s_y = u_y t_o + \frac{1}{2} a t_o^2$$

$$0 = (u \sin\theta) t_o - \frac{1}{2} g t_o^2$$

$$t_o = \frac{2u \sin\theta}{g} \quad \text{(shown)}$$

Alternative method:
Since the projectile undergoes a parabolic trajectory,

Taking upwards as positive and considering vertical motion,
Vertical component of initial velocity, $u_y = u \sin\theta$
Vertical component of final velocity, $v_y = -u \sin\theta$

$$v_y = u_y + a t_o$$

$$-u \sin\theta = u \sin\theta - g t_o$$

$$t_o = \frac{2u \sin\theta}{g} \quad \text{(shown)}$$

Alternative method:
Taking upwards as positive and considering vertical motion of the projectile,

At the highest point of it's trajectory, vertical component of velocity, $v_y = 0$

$$v_y = u_y + at$$

$$0 = u \sin\theta - gt$$

$t = \dfrac{u \sin\theta}{g}$ where t is the time taken for it to reach the peak of its trajectory

Since the projectile undergoes a parabolic trajectory, its total flight time is twice the time taken to reach the peak of its trajectory.

$$t_o = 2t = \frac{2u \sin\theta}{g} \quad \text{(shown)}$$

(b) **(i)** **1.** horizontal displacement of projectile = horizontal displacement of cart + 45 m

$$(u \cos\theta) t = vt + 45$$

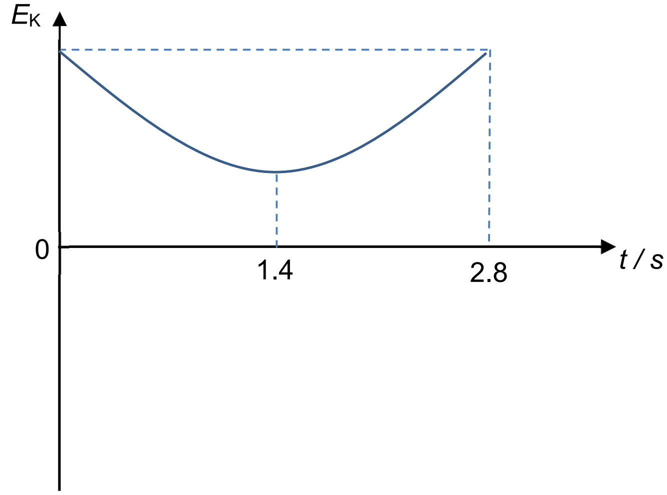
$$v = u \cos\theta - \frac{45}{t}$$

$$= u \cos\theta - 45 \left(\frac{g}{2u \sin\theta} \right)$$

$$= 35 \cos 23^\circ - 45 \left(\frac{9.81}{2 \times 35 \sin 23^\circ} \right)$$

$$= 16.08 = 16.1 \text{ m s}^{-1}$$

2.



*Shape of graph, symmetrical about minimum turning point
*Position of graph (graph above horizontal axis, correct values of *t* at minimum turning point and end of graph)

(ii) Launch the projectile with a larger speed.
OR
Lauch the projectile at a larger angle to the horizontal. (but less than 45 °)

Comments

(a)

- Students need to be very mindful when they see a question which states 'Explain your working'. While the question may seem straightforward, the need to explain the working will demand more attention and effort.
- Many students simply stated the symbols and equations, without really explaining how certain conclusions were made.
- Many who used the $s = ut + \frac{1}{2}at^2$ approached often did not give a good explanation why total displacement of the projectile upon landing is zero. Stating the reason to be that it lands at the same level of launch did not earn credit. The main point here is that the path is symmetrical about the centre. A projectile not undergoing a symmetrical path about its centre, would also have zero total displacement if it lands on the same level of launch.
- Those who used the other 2 alternative approaches did not explain that $v_y = 0$ at the peak of the path, and why $v_y = -u_y$.
- Students must remember that this is an 'explain' question and they should explicitly mention these points in words, and not expect the examiner to infer from the equations stated.
- It is also important to state the sign conventions, and be consistent with the convention for all parts of the question.

(b) **(i)** **1.**

- This part was generally well done.
- No credit was given for only finding the value of time time using the equation described in part (a).
- When calculating the displacement of the cart, many students rounded off the value to 2 s.f. (90 m) rather prematurely. Students should leave the answers in intermediate steps to more s.f. if possible.

2. The kinetic energy of a projectile is not zero at any point along its flight. Many students mistakenly drew their graphs with $E_k = 0$ in the middle.

(ii) There were several answers that suggested to decrease the angle of launch. Whie mathematically this increases the horizontal component of velocity, if the angle is too small, the object may not stay in the air long enough.

2 (a) (i) By Newton's second law,

$$T_{AB} - mg = ma$$

$$T_{AB} = 300(1.0) + 300(9.81)$$

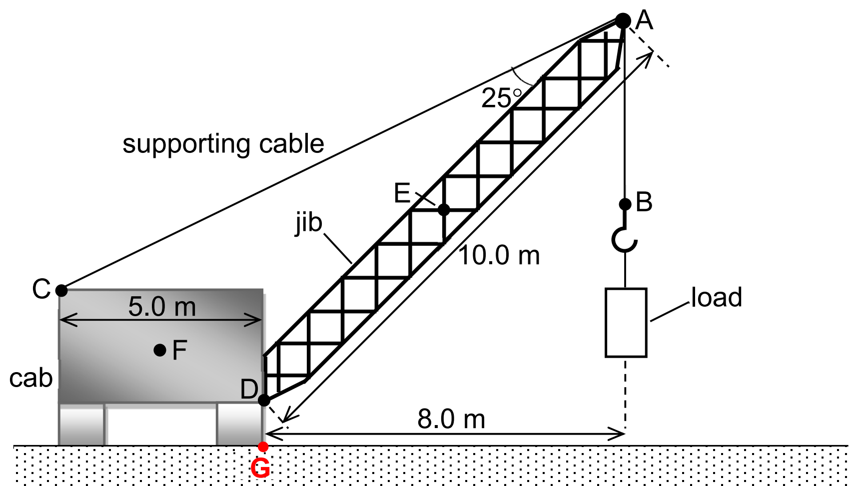
$$= 3243 = 3240 \text{ N}$$

(ii) Consider the forces on the jib.
Since the jib is in equilibrium, taking moments about D,
sum of anticlockwise moments = sum of clockwise moments

$$(T_{AC} \sin 25°)(10.0) = 2400(9.81)(4.0) + 3240(8.0)$$

$$T_{AC} = 28417 = 28400 \text{ N}$$

(b) (i)



(ii) When the crane is just about to topple about G, the normal contact force on the left wheel just goes to zero.

Considering the forces on the crane and taking moments about G,
sum of anticlockwise moments = sum of clockwise moments

$$16000(9.81)(2.5) = 2400(9.81)(4.0) + W_{max}(8.0)$$

$$W_{max} = 37278 = 37300 \text{ N}$$

(c) The force by the wind on the slab will cause it to swing/ sway/ oscillate.
This results in additional clockwise moment from the

increased tension in cable AB as the slab is displaced rightwards by the wind,

OR increased perpendicular distance from G when wind is blowing such that the slab sways away from the crane,

hence it will topple clockwise about G.

Comments

(a) **(i)** Did not accept "$T_{AB} = ma + mg$" as this does not show application of Newton's 2nd law and understanding that *ma* is the resultant of T_{AB} and *mg.* Some students erroneously equated *a* to be 10.81 m s^{-2}. Also, the directions of *T* and *ma* were opposite for quite a number of students from this group.

(ii) Common mistake was to use 300 x g x 8.0 when it should be T_{AB} x 8.0. Students should have directly used perpendicular distances 4.0 m and 8.0 m given in Fig. 2.1 for 2400g and T_{AB} respectively, instead of wasting time to further trigonometry in determining perpendicular distances.

The weight of the cab is irrelevant in this part, as this part deals with the jib itself being in equilibrium.

Some students failed to see this part as a rotational equilibrium problem.

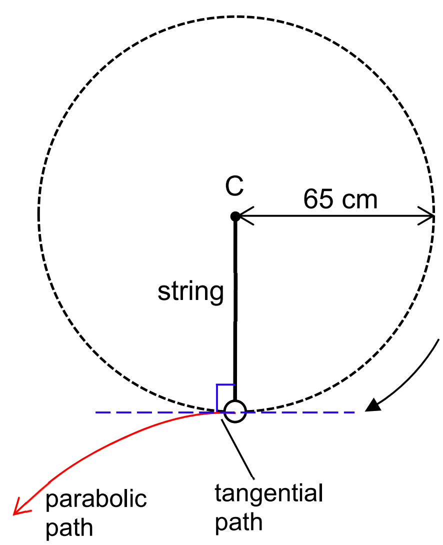
(b) **(i)** Mostly well-done.

(ii) A number of students erroneously included T_{AC} here. This is wrong, as this part deals with rotational equilibrium of the entire *crane* system. This means T_{AC}, the force exerted by the cab on the jib (and vice-versa), is an internal force in this system. There is no moment due to internal forces. Only external forces such as gravitational forces, should be considered. Note that by taking moments about G, the normal force at G yields zero moment.

Students should recognize question parts labelled (a), (b), though related to the same question, are usually independent parts, whereas (i) and (ii) under the same part are inter-dependent (i.e. answer for (ii) is usually related to (i)).

(c) Mostly well-done. Answers need to be specific in indicating concrete sways *rightward / away* from the cab, otherwise if it is leftward/ towards the cab, the weight of the slab actually contributes to additional *anticlockwise* moments about G, hence stabilising rather than toppling the crane.

3 **(a)** **(i)**



Path of the ball is such that it leaves the vertical circle horizontally to the left along the tangent of the circle (linear speed of the ball at any point along the circular path is at a tangent), followed by a parabolic path (due to gravitational force).

(ii) The resultant of the tension and weight on the ball provides the centripetal force.

$$T - mg = m\omega_1^2 r$$

$$\omega_1 = \sqrt{\frac{T - mg}{mr}}$$

$$= \sqrt{\frac{16 - 0.30(9.81)}{0.30(0.65)}}$$

$$= 8.183 = 8.18 \text{ rad s}^{-1}$$

(b) **(i)** When the angular speed increases, a larger centripetal force is required.

Since the horizontal component of the tension in the string provides for this centripetal force, tension also increases.

The vertical component of the tension also increases hence there is a resultant force upwards, which causes the ball to accelerate vertically upwards. As the ball moves upwards, θ increases but $\cos\theta$ decreases until the vertical component ($T\cos\theta$) becomes equal in magnitude to the ball's weight again.

(ii) In (a)(ii) : $\omega_1 = \sqrt{\frac{T - mg}{mL}}$ where $L = r$ is the length of the string

In (b),

$$T\sin\theta = m\omega_2^{\ 2} r = m\omega_2^{\ 2}(L\sin\theta)$$

$$T = mL\omega_2^{\ 2}$$

$$\omega_2 = \sqrt{\frac{T}{mL}}$$

Therefore ω_2 is larger than ω_1 when the string snaps at T = 16 N.

Comments

(a) **(i)** There are always crucial points to take note of in any sketch. Your sketch must show understanding of the concepts behind these crucial points.
The concepts for this part are:

- linear speed at any point along the circular motion is tangent to the circle, hence ball will leave the lowest point of the circular path horizontally
- once the string snaps, the ball only experiences gravitational force in the downwards vertical direction, hence path will be parabolic

The above have to be shown clearly on your sketch. To avoid ambiguity, it is always good to include some indication and label the different parts of the path, as shown in the given answer.

Take note that when the string snaps and the ball leaves the circle tangentially, it experiences and responds to the pull of gravity immediately. Hence the initial part of the path cannot be a long straight line.

(ii) Do remember to always start with a law or concept when answering all quantitative and qualitative questions in Physics.

For this part, the concept is that for objects in circular motion, there is a resultant force (centripetal force) on the object that is towards the centre of the circle and this force is responsible for the object's centripetal acceleration. The law that relates resultant force to acceleration is Newton's second law. Hence the starting equation, before any substitution is done, must be in the form of $F_R = ma$.

(b) (i) You need to be mindful and thoughtful of the task you are asked to do in the question, and not just throw in whatever you think without answering the objective of the question.

Here, you are asked to 'explain the observation' that the ball rises when the angular speed is increased. To 'explain' means you need to use Physics concepts / laws / principles. The question did not ask you to describe the observation (which is already stated in the question, so you will just be reiterating the question) nor should you just merely throw in a mathematical equation and describe it. We need to use Physics.

Also note that precise terms and key words / phrases need to be used with great precision as it exhibits good understanding of the concepts involved. You shouldn't be using lay man's lingo or use terms loosely. In doing your revision, remember to look out and remember the key words for each topic or concept.

For this question it is important to note that as the angular speed is increased, momentarily, the vertical component of the tension in the string is larger than the weight, and that is why there is a resultant upwards force and this explains the observation of the ball rising. Many did not bring in the concept of resultant force and stated that there is always equilibrium in the vertical direction, not realising that if this is the case, the ball will not rise.

For all circular motion, forces on the body need to be resolved in the two perpendicular directions: radially and tangentially or vertical to the plane of the circular motion. For this horizontal circular motion, unlike the vertical circular motion, you shouldn't be resolving along the string.

(ii) Many answers did not realise or clearly distinguish between the radii of circular motion for the vertical circular motion and the horizontal circular motion. Hence, many conclusions were not sound.

There were also answers that compared the maximum tension for each case. However, note that the question asked to compare the angular speeds when the string snaps i.e. when tension is specifically 16 N in both cases.

Do also note that for the horizontal circular motion, the string does not break at $\theta = 90°$. The string breaks when its tension exceeds 16 N. In fact only circular motions where $\theta < 90°$ are possible. If $\theta = 90°$, the vertical component of the tension will be zero and nothing will be supporting the weight, and weight will pull the ball downwards. So the string will never be horizontal.

Several students mentioned 'spring' instead of 'string' as given. Do be careful.

4 **(a)** **(i)** Wavelength is the distance between two consecutive points on the wave which are in phase.

Frequency is the number of oscillations per unit time made by a particle of the wave.

(ii) In a time of one period ($t = T$), the waveform moves a distance of one wavelength.

Since $f = \frac{1}{T}$,

speed $v = \frac{\text{distance}}{\text{time}} = \frac{x}{t} = \frac{\lambda}{T} = f\lambda$

(b) **(i)** The two waves must be coherent.
AND any one of the following:

- The two waves must have similar amplitude (OR similar intensity).
- The two waves must be unpolarised or polarised in the same plane for transverse waves.

(ii) **1.** The missing peaks occur when the diffraction minima of the single slit diffraction pattern coincide with the interference maxima of the double slit interference pattern.

2. single slit: $b\sin\theta = m\lambda$
double slit: $a\sin\theta = n\lambda$
Missing peaks occur when

$$\sin\theta = \frac{m\lambda}{b} = \frac{n\lambda}{a} \quad \Rightarrow \quad \frac{b}{a} = \frac{m}{n}$$

For $m = 1$ and $n = 4$, $b = \frac{1}{4}a$

$$b = \frac{1}{4}(1.2 \times 10^{-3}) = 0.30 \times 10^{-3} \text{ m} = 0.30 \text{ mm}$$

3. Using $b\sin\theta = m\lambda$

For $m = 1$, $\sin\theta = \frac{m\lambda}{b} = \frac{(633 \times 10^{-9})}{0.30 \times 10^{-3}} = 2.11 \times 10^{-3}$

$$\therefore \theta = 0.121° = \frac{\pi}{180°}(0.121°) = 0.00211 \text{ rad}$$

distance of the missing peak from the central maximum
$y = D\tan\theta = 2.5\tan 0.121° = 5.28 \times 10^{-3} = 5.3 \times 10^{-3}$ m

OR (small angle approximation)
$y = D\tan\theta \approx D\sin\theta = 2.5(2.11 \times 10^{-3}) = 5.28 \times 10^{-3} = 5.3 \times 10^{-3}$ m

OR (small angle approximation)
$$y \approx \frac{D(2\theta)}{2} = 2.5(0.00211) = 5.28 \times 10^{-3} = 5.3 \times 10^{-3} \text{ m}$$

OR (fringe separation of double slit interference pattern)
$$y = n\frac{\lambda D}{a} = \frac{4(633 \times 10^{-9}) \times 2.5}{1.2 \times 10^{-3}} = 5.28 \times 10^{-3} = 5.3 \times 10^{-3} \text{ m}$$

(iii) There will be an <u>increase</u> in the <u>intensities</u> of the interference fringes as <u>more light passes through</u> the wider slits.

AND one of the following:
There will be <u>fewer interference fringes</u> within the <u>narrower single slit diffraction envelope</u> as the <u>degree of diffraction is lesser</u> resulting in less interference.

Missing peaks are <u>nearer to the central maximum</u> because the <u>first minima of the diffraction pattern is closer to central bright fringe</u>.

Comments

(a) (i) Students need to be mindful of specific keywords/key ideas that underpins a definition. "Two points on the wave" is not the same as "two consecutive points on the wave" or words to that effect.

Students should not be using terms within a definition that have yet to be defined. Frequency is the reciprocal of the period is not accepted even if the period was further defined within the answer.

Students should not confuse units with quantities. All definitions should be in terms of quantities and not units. No credit is given if "per second" or "in one second" was used instead of "per unit time".

Students should also avoid unconventional definitions. Please refer to our notes if in doubt.

(ii) This was a straightforward question that was not well done. Many students simply stated the relationship instead of deducing the relationship. Please pay careful attention to the demand of the question by familiarizing yourself with the glossary of terms used in the physics paper.

Students should avoid the use of unconventional symbols without further definition. i.e. students who used t instead of T for period will not be given credit.

(b) (i) Students need to prioritise waves emitted by coherent sources as a key condition necessary for a well-defined interference pattern. Trivial conditions such as the two diffracted waves must overlap or of the same type will not be given credit.

(ii) 1. Many students simply gave a general explanation for why destructive interference occurs at the position of the missing peak and completely missed the context of the question.

It is important to identify the source of the waves responsible for destructive interference at the position of the missing peak. The diffraction minima is the consequence of waves from within one slit interfering destructively.

Students also need to be mindful of terms used when describing the double slit and single slit phenomena. When there are 2 or more slits involved, an interference pattern is observed at the screen. When there is only one slit (i.e. interference within a slit), a diffraction pattern is observed at the screen.

Answers such as the double slit interference pattern is limited by the single slit diffraction pattern is not given credit as it does not provide a clear explanation for the missing peak.

2. A significant handful of students were confused with the order of the interference maxima n that coincided with the position of the first diffraction minima.

Many students were confused with the different formulae and ended up with some hybrid version i.e. $b = \frac{\lambda D}{a}$ which is incorrect.

3. Many students are confused with the following 2 formulae: 1. $y = \frac{\lambda D}{b}$ and 2. $y = x_n = \frac{n\lambda D}{a}$. The distinction between slit width, b and slit separation, a appears to be fuzzy for many.

(iii) A significant handful of students misinterpreted the question and assumed it was asking for the changes to the pattern on the screen when the slit separation was increased. Students are reminded to read the question with more care especially in such context where confusion between slit width and slit separation is common.

Students need to be precise with terms used. The intensity pattern consists of both the double slit interference pattern and the single slit diffraction pattern, so it is crucial to distinguish between an interference maxima/minima and a diffraction maxima/minima. Many students simply used the term minimas/maximas without distinction. Please note that the term fringes refer specifically to the interference fringes of the double slit interference pattern.

5 (a) (i) The magnetic flux density of a magnetic field is numerically equal to the force per unit length of a long straight conductor carrying a unit current at right angles to a uniform magnetic field.

(ii) The particle is positively charged.

(b) (i) Magnetic force provides for the centripetal force.

$$Bqv = \frac{mv^2}{r}$$

$$B = \frac{mv}{rq}$$

(ii) From $B = \frac{mv}{rq}$,

since the radius has increased, B has decreased.

(iii)

$$v = \frac{Brq}{m}$$

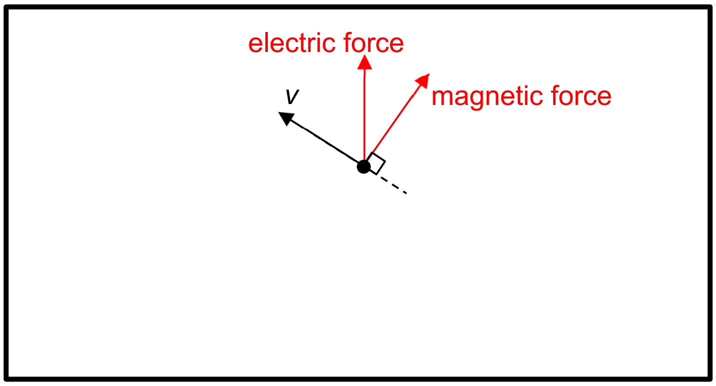
$$= \frac{(7.6\times10^{-3})(34\times10^{-2})(3.2\times10^{-19})}{6.6\times10^{-27}}$$

$$= 1.253\times10^{5} = 1.25\times10^{5}\ \text{m s}^{-1}$$

(c) Since the magnetic force is directed to the right of the particle's path, the electric force will have to be to the left of its path (so that resultant force equals zero). Electric force on a positively charged particle is in the same direction as the electric field.
Hence the electric field is to the left of the path of the particle.

(allow using "upwards" / "downwards" but direction has to be consistent with the drawing in **(c)(ii)**.)

(ii)



- Forces labelled
- Electric force in the correct direction
- Magnetic force perpendicular to *v*, in the correct direction
- Length of $F_E = F_B$

Comments

(a) (i) All underlined key words in the markscheme should be stated. As long as two or more of those points are missing in the definition, candidate will not be awarded any credit.

Students should not use numerical values in definitions of physical quantities. For example, "1A or one ampere" is wrongly used when it should be "per unit current".

(b) (ii) Students are expected to write the formula and substitute the correct numerical values into each term, before giving the final answer to the correct number of s.f.

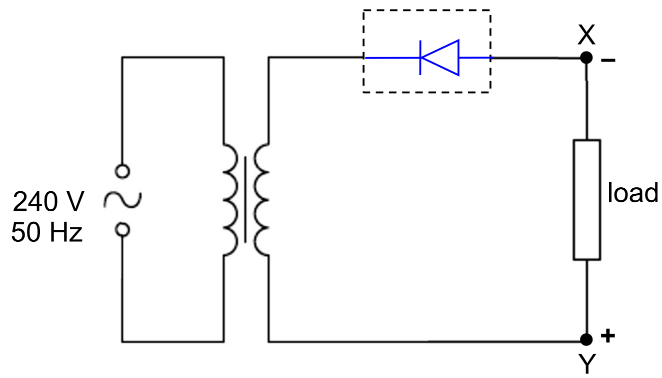
(c) (i) Students need to know that "field" is not equilvalent to "force".
Statements like "electric *field* should be opposite in direction to magnetic *force*" is not correct. The word "electric *force*" should be used instead.

Note that "electric force" is not always in the same direction as "electric field". If a negative charge is considered, the *electric force* acting on it is opposite in direction to the *electric field* that the charge is placed in.

(ii) When drawing vector diagram (or free body diagram), students need to be aware that the length of the arrow drawn is representative of the vector's magnitude. In this case, the electric force is equal in magnitude to the magnetic force as the electric and magnetic fields are adjusted according to that in part (c).

Candidates need to avoid using short-form unless it is defined in the question.
Hence, avoid using "F_E", "F_B", "F_C", "E-field" and "B-field".
Please write in full : "electric force", "magnetic force", "centripetal force", "electric field" and "magnetic field".

6 **(a)**



(b) The root-mean-square voltage of an alternating supply is the value of a steady direct voltage that would produce thermal energy at the same rate (OR deliver the same power OR same rate of energy dissipation) in a given resistor.

(c) $V_{p,max} = \left(\sqrt{2}\right) \times V_{p,rms} = \left(\sqrt{2}\right) \times 240$

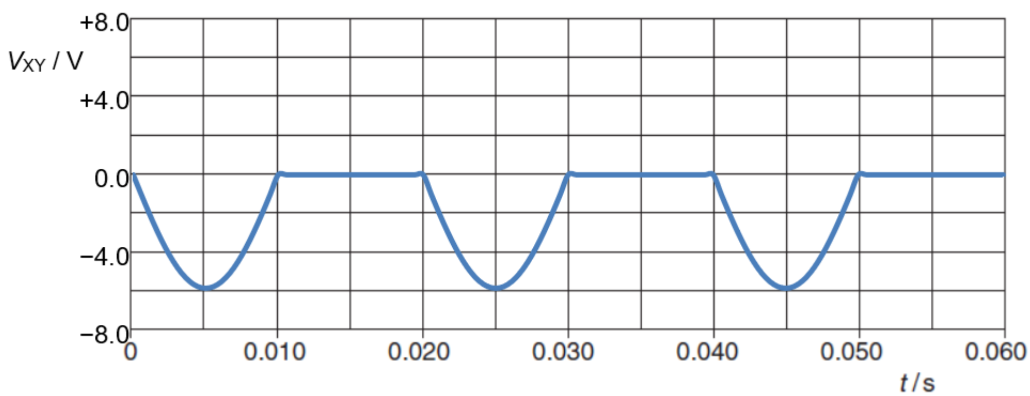
$\frac{N_s}{N_p} = \frac{V_{s,max}}{V_{p,max}}$ or $\frac{V_{s,rms}}{V_{p,rms}}$

$= \frac{6.0}{\left(\sqrt{2}\right) \times 240}$

$= 0.0177$

*Can only use r.m.s. of full wave or peak value of the secondary circuit, cannot use r.m.s. of half-wave rectified.

(d)



- Half-wave rectified sinusoidal waveform below the *t*-axis.
- Peak value of –6.0 V
- Period of 0.020 s

(graph can be translated horizontally)

(e) **(i)** For half-wave rectification,

$$V_{rms} = \sqrt{\frac{V_0^{\,2}/2 \times T/2}{T}} = \frac{V_0}{2}$$

$$= \frac{6.0}{2} = 3.0 \text{ V}$$

(ii) mean power $\langle P \rangle = \frac{V_{rms}^2}{R} = \frac{3.0^2}{4.0} = 2.25 \text{ W}$

Comments

(a) A handful of students did not know what the symbol for a diode is like. Students must remember the symbols for the various electrical components covered in the syllabus.

Many students leave gaps between the diode and the rest of the circuit. This implies an open circuit and therefore incorrect.

(b) Missing keywords such as “steady” in “steady direct voltage” and “given or same” in “a given resistor” are commonplace.

Use of wrong or inappropriate keywords or terms such as “component” instead of “resistor”, “heating effect” instead of “power dissipated” or “rate of thermal energy produced” and “direct current voltage” are also quite common.

Some students merely showed how to mathematically determine the r.m.s. voltage rather than explain what is meant by rms voltage.

(c) The most common mistake here is that students failed to convert primary rms voltage to its peak value when the secondary peak voltage of 6.0 V is used in calculating the turns ratio or they did not convert the secondary peak voltage to its rms value when they used the primary rms voltage.

Some students stated the answer in terms of a fraction. Be reminded to state the numerical answer for ratios in decimal numbers to the correct sf instead.

(d) Many students incorrectly drew a full wave sinusoidal waveform and many others drew positive half-wave rectified sinusoidal waveform. The half-wave rectified waveform should be drawn in the negative domain as V_x is lower than V_y and that $V_{xy} = V_x - V_y$.

A handful of students did not draw V_{xy} when it is zero for one half a complete cycle (no visible line can be seen). Some students, for unfathomable reasons, drew square waveforms.

(e) **(i)** The most common mistake in this part is calculating rms V_{xy} using $V_{rms} = \frac{6.0}{\sqrt{2}}$ which is for full wave sinusoidal function when V_{xy} is actually half-wave rectified.

Some students made the careless mistake of not taking the square root of the mean square value of V_{xy}.

7 **(a)** This is because scattering forces, acting only in the positive axial direction (i.e. in the direction of the beam), will tend to displace and push the particle out of the beam waist.

The particle needs to experience a greater magnitude of gradient forces acting towards the centre of the beam waist (especially in the negative axial direction, i.e. attracting the particle towards the equilibrium position), so that the displaced particle can remain trapped.

(b) **(i)** 0.70×10^{-7} m or 7.0×10^{-8} m (half the smallest square, 2 s.f.)

(ii)

$$k = -\text{gradient} = -\frac{\left(2.50\times10^{-12}\right)-0}{\left(-0.50\times10^{-7}\right)-0}$$

$$= -\left(-5.0\times10^{-5}\right) = 5.0\times10^{-5}\ \text{N m}^{-1}$$

(2 or 3 s.f.)

(iii) **1.** From Newton's second law, the restoring force is proportional to acceleration.

Therefore, for the restoring force described by Hooke's Law, the magnitude of the acceleration is proportional to *r*.

The negative sign implies that the acceleration is directed towards the equilibrium position (i.e. $r = 0$) (OR acceleration is opposite in direction to *r*).

This satisfies the condition for SHM where $a \propto -r$.

*Allow if explanation uses the straight line part of the graph in Fig. 7.3 with negative gradient and through origin and relates force to acceleration.

2. For SHM, $a = -\omega^2 r$ where ω is the angular frequency

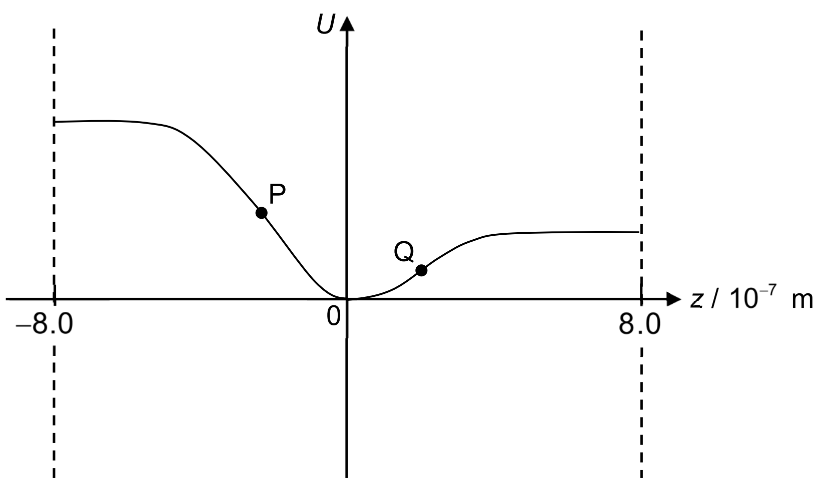
$F_R = ma$

$-kr = -m\omega^2 r$

$\omega^2 = \left(2\pi f\right)^2 = \dfrac{k}{m}$

$f = \dfrac{1}{2\pi}\sqrt{\dfrac{k}{m}} = \dfrac{1}{2\pi}\sqrt{\dfrac{5.0\times10^{-5}}{1.50\times10^{-14}}} = 9189 = 9190\,\text{Hz}$

(c)



*Shape of the curve, *U* is zero in the middle at the minimum turning point
*Left side of curve has a steeper gradient and a greater final *U* value compared to right side of curve
*P and Q labelled on steepest parts of graph

(d) **(i)** The photon, which carries momentum, experiences an <u>impulse due to the bead radially to the left</u>.

By the principle of conservation of momentum, the bead experiences an impulse radially to the right such that the radial momentum remains zero.

By Newton's second Law, this rate of change of momentum (impulse) means the bead experiences a force radially to the right.

OR

The photon, which carries momentum, experiences an impulse due to the bead radially to the left.

By Newton's second Law, this rate of change of momentum (impulse) means the photon experiences a force radially to the left.

By Newton's third Law, the bead must therefore experience a force equal in magnitude to the right due to the photon.

(ii) **1.**

$$p = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34}}{960 \times 10^{-9}}$$
$$= 6.91 \times 10^{-28} \text{ kg m s}^{-1}$$

2.

$$\text{impulse} = \Delta p = p_f - p_i$$
$$= \left(6.91 \times 10^{-28}\right) \sin 32.0^\circ - 0$$
$$= 3.66 \times 10^{-28} \text{ kg m s}^{-1}$$

3.

$$\text{impulse} = |\Delta p| = |p_f - p_i|$$
$$= \left|\left(6.91 \times 10^{-28}\right)\cos 32.0^\circ - \left(6.91 \times 10^{-28}\right)\right|$$
$$= \left|-1.05 \times 10^{-28}\right| = 1.05 \times 10^{-28} \text{ kg m s}^{-1}$$

(e) The increase in temperature can cause irreversible damage to the sample's biological material.

Increasing the temperature of the medium causes the particles in the medium to vibrate faster / move faster / increase the average kinetic energy.
Hence, they bombard the glass bead with greater forces at a higher rate, which could kick the bead out of the trap / make trapping less feasible / less effective. (Increased effect of Brownian motion.)

Comments

(a) Students need to show evidence of understanding that the gradient forces are attractive (they act to push the particle back to the centre of the beam waist) while the scattering forces, acting in one direction, will generally be acting to push it out of the beam waist and towards the condenser. Hence, to remain trapped, there needs to be a net force restoring the trapped particle back to its equilibrium position.

Some of the answers that are not correct would include talking about a "component" of the gradient force (there are separate forces acting in all directions, they are not components of one another), or that the gradient and scattering forces have to give a net force of zero (the net force should be towards the equilibrium, a net force of zero could mean the particle can move at a constant velocity out of the beam waist).

Note: as the particle's displacement from equilibrium increases, the gradient force will also increase. However, the attractive force will only increase to a point before it decreases again, as can be seen from the diagrams given in the question where there is a value for the maximum force along each direction. The scattering force on the other hand acts in the forwards axial direction, pushing the particle out of the beam waist towards the condenser. Hence, the particle is actually most likely to escape the beam waist towards the forward axial direction. If the gradient forces are not able to increase to a large enough value when the particle is displaced in the forwards axial direction, the scattering forces will be more than the attractive forces and the particle will escape.

(b) **(i)** Answer should be quoted to half the smallest square: hence, 2 s.f. (either 0.70×10^{-7} m or 7.0×10^{-8} m).

(ii) Coordinates quoted in calculation for gradient should be given to half the smallest square as well. Will allow answers that use just one point on the appropriate part of the graph for finding k (i.e. point must be taken on the part of the graph that still obeys Hooke's Law).

(iii) **1.** For three marks, students are expected to clearly AND explicitly state the relationship between force and acceleration, either via F = ma or at the very least that force is proportional to acceleration.

The remaining two marks are for linking Hooke's Law to the definition of simple harmonic motion, that the acceleration is proportional to displacement from equilibrium, and that the direction of acceleration is always pointing towards the equilibrium or opposite direction to displacement.

2. ECF is given if k value was incorrect in **(b)(ii)**. Will allow students to quote $\omega^2 = \frac{k}{m}$ as **(b)(iii)1.** already implies students know that $a = -\frac{k}{m}r = -\omega^2 r$. However, in general, students should learn to derive such an expression for other questions.

(c) Very poorly done in general. Many students are unable to produce the correct graph, likely because they cannot link $F = -\frac{dU}{dr}$ or $\Delta U = -\int F\,dr$ to graph drawing. Recommendation is for students to start from $F = -\frac{dU}{dr}$ and work backwards. E.g. If F is zero, $\frac{dU}{dr}$ is zero. If F is positive, $\frac{dU}{dr}$ must be negative, and if F is negative, $\frac{dU}{dr}$ must be positive. The peak values of F will correspond to the steepest gradients in the U – r graph, at P and Q.

(d) **(i)** Many students got distracted or confused by refraction – actually, this question is nothing more than just momentum conservation and then linking rate of change of momentum to force via Newton's Second Law.

Full credit cannot be given to students who displayed evidence of incorrect conceptual understanding or incorrect physics. For example, some students used the relation $p = mv$ when referring to the momentum of photons, which is not appropriate as $m = 0$ for photons.

The best answers are able to show a CLEAR FLOW of ideas in their logical argument and invoke the correct law / principle at the right moment, instead of jumping all over the place. E.g. photon gains momentum towards the left, conservation of momentum means the bead gains momentum to the right, this rate of change of momentum of the bead implies, by N2L, that a force is exerted on the bead to the right.

(ii) **1.** Straightforward question, however some students either cannot recall the de Broglie relationship for momentum and wavelength of a photon (e.g. using $p = \frac{\lambda}{h}$ instead) or tried to use $p = mv$, where m is the mass of a proton or electron.

2. ECF is given if momentum was calculated wrongly in (d)(ii)1. However, credit cannot be given if student quotes $\Delta p = m\Delta v$ in the working as $m = 0$ for photons. It shows evidence of wrong conceptual understanding and wrong physics.

3. ECF is given if momentum was calculated wrongly in (d)(ii)1. However, credit cannot be given if student quotes $\Delta p = m\Delta v$ in the working as $m = 0$ for photons. It shows evidence of wrong conceptual understanding and wrong physics.

Most common error here is to only find $p\cos 32°$ as the impulse, forgetting that the photon has an initial momentum in the axial direction.

(e) As stated (hinted) in the question, the heating induced by the laser affects both the sample and the particles of the medium surrounding the glass bead. Hence, students are expected to explain what adverse effects might result due to the increase in temperature.

As this is not a biology exam, students will not be marked on the details given for the type of damage the sample might experience. However, all types of damage (e.g. denature, change in structure, change in chemical composition, disruption to chemical and biological processes, just generic “damage”) would be classified under the same point. Only exception is sample “burning” – the increase in temperature is actually very small (less than 1 K), so the sample burning in flames is unlikely.

Very few students were able to properly explain the second effect of laser induced heating, which is related to increased bombardment of the medium particles on the glass bead due to increase in temperature, which might cause the bead to be kicked out of the beam waist (or make the study of the sample difficult). Students should relate this to their knowledge of how temperature is linked to average microscopic kinetic energy of particles, and also their knowledge of Brownian motion (pollen grains suspended in water exhibit erratic motion due to collisions with randomly moving water molecules). Note that answers involving the sample or glass bead gaining kinetic energy and escaping were not accepted as the main dominant effect here is the thermally induced Brownian motion – the erratic motion and increased random forces felt by the glass bead and sample due to the medium particles colliding with it is what reduces the effectiveness of the trapping. The gain in temperature of the glass bead and sample increases its microscopic kinetic energy but does not contribute to its bulk movement or bulk kinetic energy.

Finally, answers that involved the glass bead melting, cracking, bursting into flames, the machine bursting into flames, increased cost due to machine inefficiency (heat loss), heating posing danger to the scientist, heat causing medium to evaporate were all not accepted. As mentioned, the temperature increase due to this laser heating is actually rather small (less than 1 K). Students should be able to infer that since this method has been successfully used to study biological samples (as stated in the preamble). Hence, it is unlikely that a method which routinely causes machines to burst into flames can go on to win a Nobel Prize in Physics.

Final note: Generally, the experiment is usually conducted under rather cold conditions so as to reduce the motion of the particles in the medium, which is why an increase of 1 K in temperature can be significant.