2021 Raffles Institution Preliminary Examinations – H2 Physics
Paper 2 – Suggested Solutions

1 **(a)** **(i)** When bodies in a system interact, the <u>total momentum of the system remains constant</u>, — B1
provided <u>no net external force</u> acts on it. — B1

> It is important to include the word "**net**". There can be external forces acting on the system. As long as the "**net**" external forces is zero, conservation of momentum can be applied.
>
> Note that conservation of momentum is not only confined to *collision* problems. Hence no credit is given for simply stating "Total momentum before and after *collision* is constant".
>
> Also, there is no need to confine the discussion to just "two bodies".

(ii) Relative speed of approach = relative speed of separation

$u - (-u) = v_B - v_A$

$2u = v_B - v_A$ .... (1) — B1

Conservation of momentum

$m_A u - m_B u = m_A v_A + m_B v_B$ .... (2) — B1

$m_A \times (1) + (2)$: $(2\, m_A u) + (m_A u - m_B u) = (m_A v_B - m_A v_A) + (m_A v_A + m_B v_B)$ — B1

$3\, m_A u - m_B u = m_A v_B + m_B v_B$

$$v_B = \frac{3m_A - m_B}{m_A + m_B} u$$

> Some candidates worked backwards from the result and quote some expressions. No credit is given if there are no basis and no explanation given for these expressions.
> Candidates who tried to use conservation of kinetic energy will end up with very messy expressions and most likely do not obtain the result needed. For elastic collisions, using the relative speed relationship is neater.
>
> The sign convention is given in the question (taking right to be positive). Candidates using the wrong convention may still end up with the required answer, but no credit is given for such case, as candidates failed to follow the instructions given.

(b) **(i)**

$$v_{tennis} = \frac{3m_A - m_B}{m_A + m_B} u = \frac{3(0.62) - (0.059)}{0.62 + 0.059}(4.4)$$
$$= 11.7 \text{ m s}^{-1}$$ — B1

> Some candidates confused the collision between the basketball and tennis ball with that of the collision with the ground.

(ii) The impact force is much greater than the weight of the tennis ball / basketball. (Hence, gravitational force, which is an external force, is neglected when applying conservation of momentum.) — B1

> The scenario in part **(b)** (which is a vertical motion) is an extension to the result in part **(a)** (which is a horizontal motion). Hence the force of gravity (which is an external force) may made the application of conservation of momentum invalid. The

reason why it may still be applied is that the impact force is much larger than the gravitational force (weight) of the objects. This is due to the short time duration of impact between the two objects.

Repeating what the question has already provided will not earn the credit, e.g. stating that the "speed of the basketball before and after impact with the ground is the same" will not earn any credit.

Simply stating that there are no external forces is also not correct, as gravitational force *is* an external force.

Stating that "gravitational force is negligible" is not good enough. It should be "negligible compared to the impact force".

"Friction" is also not a consideration as the objects are **not** moving sideway between themselves.

As the objects are "released" from a height, they should fall vertically (and not at an angle). Hence stating "head-on" or "collide vertically" will not get any credit as these are trivial observations in this context.

Note that the conservation of momentum is obtained from Newton's 2nd and 3rd Law. There is no consideration of energy involved here. Hence candidates stating that the assumption of no loss of energy do not get the credit.

Other trivial suggestions like mass not changed, there is no wind, etc, do not get the credit.

(iii) Basketball is much greater in mass as compared to the ball, hence m_B is negligible compared to m_A.

Using **(a)(ii)**,

$$v_B \approx \frac{3m_A}{m_A}u \qquad \text{M1}$$

$$= 3u$$

$$= 3(4.4)$$

$$= 13.2 \text{ m s}^{-1} \qquad \text{A1}$$

Candidates should make effort to explain their workings.

2 **(a)** The moment of a force about a point is defined as the <u>product of the force and the perpendicular distance of the line of action of the force from the point</u>. B1

The definitions in the lecture notes should be memorised properly. They are already as concise as they can be without losing any significant meaning.
Also do try to read through the sentence after writing as there were many cases of "distance from the point to the pivot" appearing in the definitions.

(b) Since the airplane is travelling at constant speed, it is in equilibrium

Vertically: $L = W = mg = (1.5\times10^5)(9.81) = 1.47\times10^6$ N

Horizontally: $T = D = 8.0\times10^6$ N C1

clockwise torque = anti-clockwise torque

$T\times y = W\times(0.75)$

$(8.0\times10^5)y = (1.47\times10^6)(0.75)$ M1

$y = 1.38$ m A1

Many students did not specify their pivot and seemed to either be calculating torque (instead of moment as stated in their solutions). These two quantities are inherently the same but would be good to specify what the calculation is correctly.

(c) As the airplane accelerates forward, the <u>box will tend to move at its original velocity</u>. M1
Hence, the box will tend to <u>move backwards relative to the airplane floor</u>.
<u>Friction</u> on the box by the floor therefore acts <u>forward</u> (to oppose this relative motion). A1

Simply stating N1L followed by a "hence" does not make an explanation valid.

Many students correctly stated N1L but did not give any context as to what was happening to the box, and then followed up by using N2L to explain the direction of friction. This is not answering the question.

It is necessary to state the movement of the box with reference to the plane.

Many students incorrectly stated that there is no resultant force on the box as the box is stationary (wrt to the plane) or that there is a backward resultant force acting on the box as the plane accelerates.

(d) Applying principle of moments, taking pivot at the C.G.,

$(2.0\times10^5)10 + (2.0\times10^5)20 = P(30\cos30°)$ M1

$P = 2.31\times10^5$ N A1

Many students incorrectly resolved the distance/perpendicular component of P.

3 **(a)** In one second, the volume of air that is swept by the blades is

$V = A\times v(1)$

$= \pi(50)^2\times20$ M1

$= 1.57\times10^5$ m^3 A1

Most students calculated the volume flow rate correctly. A few candidates do not know the formula for the area of a circle.

(b) In 1 s, mass $= \rho V$

$= 1.20\times1.57\times10^5$

$= 1.88\times10^5$ kg B1

This part presents little challenge to most students.

(c) **(i)** Rate of loss KE $= \frac{1}{2}\left(\frac{dm}{dt}\right)\left(u^2 - v^2\right)$

$= \frac{1}{2} \times 1.88 \times 10^5 \times \left(20^2 - 15^2\right)$ M1

$= 1.65 \times 10^7$ W A1

A number of students wrongly wrote the loss in KE as $\frac{1}{2}m\left(u - v\right)^2$ when it is supposed to be $\frac{1}{2}m\left(u^2 - v^2\right)$. Some students use the "–" sign excessively or carelessly omitting them for convenience and were penalised. It will be helpful to remember that:
"Gain" = "Final – Initial"
"Loss" = "Initial – Final"
This will save you from introducing the "–" sign haphazardly.

(ii) Force $= \frac{dm}{dt} \times \left(u - v\right)$ M1

$= 1.88 \times 10^5 \times \left(20 - 15\right)$

$= 9.42 \times 10^5$ N A1

Quite a number of students applied the familiar "$F = v\frac{dm}{dt}$" here wrongly, with v = 20 or 15. A significant number of students misunderstood the deceleration of the wind to be 5 m s^{-2} (calculated using $a = \frac{u - v}{t}$). The actual situation experienced by the wind when it reaches the windmill is very different. The deceleration from 20 m s^{-1} to 15 m s^{-1} happens over a time much shorter than 1 second, while the mass of wind undergoing the deceleration at any instant is much less than the value obtained in **(b)**. In other words, while $F = ma$ is valid, the m is not 1.88 ×10^5 and the a is not 5. Students who solve this part by assuming 1.88 × 10^5 kg of air undergoes deceleration of 5 m s^{-2} **are not given any credit despite obtaining the correct numerical answer** because their solution applies to a different scenario. The correct method is to consider the momentum of 1.88 × 10^5 kg of air just before it reaches the windmill with just after passing the windmill.

Students might have come across questions that used $F = u\frac{dm}{dt}$ to obtain the force of impact etc where u is simply the speed of the object before impact. So why is it that in this question $u \neq 20$ m $^{-1}$? This is because in those cases, the speed of the objects become 0 after the impact, so $u - v = u$. In other words, it has always been $F = \left(u - v\right)\frac{dm}{dt}$.

Another point to take note is that in Force $= \frac{dm}{dt} \times \left(u - v\right)$, both $\frac{dm}{dt}$ and $u - v$ refer to the wind. So obviously the "Force" has to be the force **acting on the wind** (by the windmill blades). Many students mistook it as force exerted **on the blades** by the wind, and then invoking Newton's Third Law to say that force acting on the wind has the same magnitude or to get rid of the "–" sign in their answer that they do not know how to handle.

(d) The rate of loss of KE is equal to the product of the force and average wind speed. B1

This part serves to remind everyone that in the formula $P = Fv$, the P is the instantaneous power and the v is the instantaneous speed, and if the speed of the object (in this case, the wind) is changing, then v should be replaced by the average speed. In other words, the answer of part **(c)(ii)** can be obtained using $P = Fv$ using $P = 1.65 \times 10^7$ W and $v = 17.5$ m s^{-1}.

4 **(a)** **(i)** By the principle of conservation,

gain in KE = loss in GPE B1

$$\frac{1}{2}mv^2 - 0 = mg\Delta h$$

$$\frac{1}{2}v^2 = (9.81)(0.30 - 0.30\cos 25°) \quad \text{B1}$$

$$v = 0.7426$$

$$v = 0.74 \text{ m s}^{-1}$$

Some students tried to use the equations for simple harmonic motion to solve this problem and obtained a value of 0.725 m s^{-1}. The motion of a pendulum can be regarded as simple harmonic only if the angle of oscillation is small. Since 25° is not a small angle, this approach cannot be used.

(ii)

$$T - mg = \frac{mv^2}{r}$$

$$T = \frac{(0.010)(0.74)^2}{0.30} + (0.010)(9.81) \quad \text{M1}$$

$$T = 0.116 \text{ N} \quad \text{A1}$$

Some students failed to recognise that this is a question on circular motion and simply equated the tension to the weight of the bob. Some students thought that only tension acts on the bob and incorrectly equated the tension to the centripetal force.

(iii) When the bob passes point B, the <u>radius of the circular motion is smaller and the speed of the bob is the same</u>. B1

Since the <u>centripetal force is now larger</u>, the tension is larger. B1

Many students failed to state that the speed of the bob just after passing point B is the same. Students who incorrectly stated that tension = $\frac{mv^2}{r}$ will not be given any credit. There is no error carried forward for applying the wrong physics concepts in **(ii)** for this part.

(b) **(i)** Vertically,

$$T\cos\theta = mg$$

$$(0.20)\cos\theta = (0.010)(9.81)$$ M1

$$\theta = 60.6°$$ A1

Candidates are reminded to show the relevant equations, followed by substitution of values before evaluating the final answer.

(ii) Horizontally,

$$T\sin\theta = mr\omega^2$$

$$(0.20)\sin\theta = (0.010)(0.30\sin\theta)\omega^2$$ M1

$$\omega = 8.16 \text{ rad s}^{-1}$$ A1

Common mistakes include using "30" instead of "0.30"; using 0.30 as the radius, rather than 0.30 sinθ. Candidates who use T (instead of $T\sin\theta$) with length of string as the radius (instead of $L\sin\theta$) will still end up with the correct answer. However, no credit is given as the workings are still incorrect.

5 **(a)** **(i)**

$$F_E = \frac{Qq}{4\pi\varepsilon_0 r^2}$$

$$= \frac{(3.2\times10^{-9})(1.6\times10^{-9})}{4\pi\varepsilon_0(0.050)^2}$$ M1

$$= 1.84152\times10^{-5}$$

$$= 1.84\times10^{-5} \text{ N}$$ A1

This question was generally well answered.

(ii) $T\cos10° = W$

$$T = \frac{1.5\times10^{-4}}{\cos10°} = 1.523\times10^{-4}$$ M1

$$F = F_E + T\sin10°$$ M1

$$= 4.48642\times10^{-5}$$

$$= 4.49\times10^{-5} \text{ N}$$ A1

A common mistake made was to subtract the horizontal component of tension from electric force to obtain magnitude of force F. Many students mistook the weight given as mass.

(iii) The <u>charges in the two spheres will be repelled/redistributed</u> to the two far sides of the sphere. B1

The <u>distance between the two charges will larger than 0.050 m</u> and the <u>electric force will be smaller</u>. <u>F will be smaller</u> since the horizontal component of tension remains the same. B1

(b) The gain in kinetic energy is equal to loss in gravitational potential energy and loss in electric potential energy. B1

Other acceptable answers:

There is work done by the electric force.

There is a change in the electric potential energy.

A common mistake was to state that there is an increase in electric potential energy.

6 (a) As the rod falls, the area enclosed by the rod and the frame decreases and the flux linkage decreases. By Faraday's law, an e.m.f. is induced. B1

Since the circuit is closed, there is an induced current. B1

There will be a magnetic force acting on the current-carrying rod as it is perpendicular to the magnetic field. B1

The question asks why a magnetic force exists. Many students attempted to explain this using Lenz's law or the left-hand rule (LHR), which is not accepted. Lenz's law and LHR concern only the direction of the magnetic force, but do not explain why a magnetic force exists. For that you need to apply either Faraday's law (the first answer above) or motional e.m.f. (the second answer).
Note that Faraday's law concerns only the induced e.m.f., not the current. To have an induced current, you need to mention the closed circuit. To have a magnetic force acting on the current, you need a magnetic field with a perpendicular component to the current. Many students ignored these crucial points in their answers. Also, as a general rule of thumb, you need to quote the name of the law that you apply (or you will be penalized), but you do not need to restate the entire law unless you are explicitly asked to.
Many students stated that as the rod moves down, electrons move with the rod downwards, hence will experience a magnetic force (to the left), which is true. This is the explanation of the motional e.m.f.. But some of them went on to say that this is the magnetic force acting on the rod, which is wrong. Although such magnetic forces act on the free electrons in the rod, the positive ions are also moving down with the rod, hence experience magnetic forces in the opposite direction (to the right). These two magnetic forces exactly cancel, hence there is no net magnetic force in the horizontal direction. The magnetic force acting on the rod is due to the current in the rod, and is in the vertical direction!
Some students explained the magnetic force acting on the rod in terms of the interaction between the external magnetic field and the induced magnetic field around the rod, which is wrong. The magnetic force ($F = BIL$) is between the external magnetic field (B) and the current-carrying rod (IL), not between the two magnetic fields. This is similar to the electric force between two point-charges ($F_E = \dfrac{qQ}{4\pi\varepsilon_0 r^2} = q \times \dfrac{Q}{4\pi\varepsilon_0 r^2} = q \times (\text{E-field due to } Q)$) , which is between a charge (q) and the electric field of another charge (E-field due to Q). It is not between the electric fields of the two charges!

(b) The downward motion of the rod causes change in the magnetic flux linkage in the circuit. According to Lenz's law, the magnetic force acting on the induced current must oppose this downward motion. M1

Hence the magnetic force is upwards. A1

Note: one can also work out first the direction of the current flow using Lenz's law, then the direction of the magnetic force using FLHR.

Some students did not quote the name of the law (Lenz's law). Some students did not STATE the direction of the force. Note that you need a correct explanation (M1) before you can score the A1 (state the direction).

(c) magnetic force = $BIL = B \times \frac{\text{e.m.f.}}{R} \times L = B \times \frac{BLv}{R} \times L = \frac{B^2L^2v}{R}$ B1

The highest speed is reached when the upward magnetic force and weight of the rod are equal in magnitude. C1

$$F_B = W$$

$$BIL = mg$$

$$\frac{B^2L^2v}{R} = mg$$

$$v = \frac{mgR}{B^2L^2} = \frac{0.15 \times 9.81 \times 2.0}{0.35^2 \times 2.0^2}$$ M1

$$v = 6.01 \text{ m s}^{-1}$$ A1

Many students wrote wrong equations such as $F_B = BLv$, while in truth induced e.m.f. = BLv and $F_B = BIL$. One way to tell them apart (if you could not remember) is to look at the units. For the former equation, both sides should have the unit of e.m.f. (volts), whereas for the latter both sides should have the unit of force (newtons). To solve this problem, it is crucial to realize that maximum speed is the terminal speed, at which the magnetic force and weight are equal in magnitude.

7 (a) $f = \frac{1}{T} = \frac{1}{20 \times 10^{-3}} = 50 \text{ Hz}$ B1

(b) $V_{XY,rms} = \frac{17.0}{\sqrt{2}} = 12.0 \text{ V}$ B1

(c)

$$\frac{N_P}{N_S} = \frac{V_P}{V_S}$$

$$\frac{4000}{200} = \frac{V_P}{12.02}$$ M1

$$V_P = 240 \text{ V}$$ A1

(d) There is a potential difference across the resistor for only half of each cycle.

mean power = $\frac{1}{2} \times \frac{V_{rms}{}^2}{R}$

$$= \frac{1}{2} \times \frac{12.02^2}{4.8}$$ M1

$$= 15.1 \text{ W}$$ A1

Many students failed to consider the effect of diode on the p.d. across the resistor.

(e) For first half of a cycle, from <u>5 ms to 15 ms</u>, the diode is <u>forward biased</u> and <u>the p.d. across the load resistor is the same as V_{XY}</u>. B1

For the second half of a cycle, from <u>15 ms to 25 ms</u>, the diode is <u>reverse biased</u> and <u>the p.d. across the load resistor is zero</u>. B1

Most students failed to use the terms "forward biased" and "reverse biased" when referring to the diode.
Many students have difficulty in describing p.d. across the resistor when the diode is forward biased, giving answers such as "p.d. increases and then decreases", "the p.d. varies sinusoidally", "the p.d. is half-wave rectified" or "the p.d. is positive", without any reference to time or the peak value. A correct description is "From 5 ms to 10 ms, the p.d. increases sinusoidally from 0 V to 17 V. From 10 ms to 15 ms, the p.d. decreases sinusoidally from 17 V to 0 V."
A common mistake is to state that the current flows only in one direction without stating what the direction is.
Another common mistake is to state that the current flows from X to Y. Students need to state whether the current flows from X to Y across the secondary coil or the resistor. An alternative is to state that the current flows clockwise or anti-clockwise from X to Y.

8 **(a)** $T = 4.70 - 1.20 = 3.50$ days B1

(b) **(i)** Gravitational force between both stars provides the centripetal force required for the circular motion. *(this statement is sufficient to get 1 mark for the explanation part)* B1

$$\frac{GM_SM_P}{d^2} = M_P y\omega^2$$ B1

$$M_S = d^2 y\left(\frac{2\pi}{T}\right)^2\left(\frac{1}{G}\right)$$

$$M_S = \left(\frac{4\pi^2}{G}\right)\frac{yd^2}{T^2} \quad \text{(shown)}$$

$$\frac{GM_SM_P}{d^2} = M_S x\omega^2$$ B1

$$M_P = d^2 x\left(\frac{2\pi}{T}\right)^2\left(\frac{1}{G}\right)$$

$$M_P = \left(\frac{4\pi^2}{G}\right)\frac{xd^2}{T^2} \quad \text{(shown)}$$

It is important to show clearly the equations where the gravitational force provides the centripetal force for both the star and the planet separately.

For e.g. if you are considering planet of mass M_p orbiting the star, the equation should be $\frac{GM_SM_P}{d^2} = M_P y\omega^2$ where M_p will cancel on both sides to get $\frac{GM_S}{d^2} = y\omega^2$. There are some students who thought that $\frac{GM_S}{d^2} = y\omega^2$ means they are considering the star of mass M_S moving in circular motion because they only saw M_S in the equation.

Do note that the gravitational forces between the star and the planet is due to their masses at a distance d apart. Their orbital radius is not d but x and y instead. Hence stating $\frac{GM_SM_P}{d^2} = M_P d\omega^2$ is wrong.

(ii) $M_S + M_P = \left(\dfrac{4\pi^2}{G}\right)\dfrac{yd^2}{T^2} + \left(\dfrac{4\pi^2}{G}\right)\dfrac{xd^2}{T^2}$ B1

$= \left(\dfrac{4\pi^2}{G}\right)\dfrac{d^2}{T^2}(y + x)$

Since $d = x + y$

$M_S + M_P = \left(\dfrac{4\pi^2}{G}\right)\dfrac{d^3}{T^2}$ (shown)

(c) $M_S + M_P = \left(\dfrac{4\pi^2}{G}\right)\dfrac{d^3}{T^2}$

$2.28 \times 10^{30} = \left(\dfrac{4\pi^2}{6.67 \times 10^{-11}}\right)\dfrac{d^3}{(3.50 \times 24 \times 3600)^2}$ M1

$d = 7.06 \times 10^9$ m A1

Surprisingly, almost 40% of the students forgot to square period in their calculations! There are also several students who forgot to convert 3.5 days to seconds.

(d) $v_P = \dfrac{2\pi r}{T}$

$= \dfrac{2\pi \times 7.062 \times 10^9}{3.50 \times 24 \times 3600}$ B1

$= 1.467 \times 10^5 = 1.47 \times 10^5$ m s^{-1}

As the mass of Osiris is negligible, distance *x* is also negligible. Hence the orbital radius of Osiris can be assumed as *d*. There are some students who took extra steps to find *y* and realised that it is the same as *d* up to 3 s.f.

(e) Since the center of mass of the system is stationary, the momentum of the system must be zero.

$2.28 \times 10^{30} \times 84.3 + M_P \times (-1.467 \times 10^5) = 0$ M1

$M_P = 1.31 \times 10^{27}$ kg A1

(f)
1. The plane of orbit of the planet must be such that the transit can be observed from Earth. B1
2. The size of the planet must be large enough to block enough starlight. B1
3. The time of transit across the star must be long enough to be detectable.
4. Exoplanets with very long periods may not be detected as the chances of a transit happening while the stars are under observation is very small or may not happen in our lifetime.
5. The brightness of the star must be large enough so that a change in the brightness can be detected.
6. Rogue planets cannot be detected as they do not orbit around any stars.

The question is asking for limitations of the transit method in detecting exoplanets in <u>general situations</u>. The phrasing of the solutions is important. Marks were not awarded if solutions focused only on the detection of Osiris. Marks were also not awarded for commenting on the

accuracy of determining period of the exoplanets as the question is focused on detecting exoplanets, not calculating mass or period of the exoplanet.

Space debris blocking the star are not accepted as these debris only block the star once and is not periodic. It is still possible to observe periodic changes in the luminosity of the star when there is an exoplanet orbiting it.

Other exoplanets blocking the star are not accepted as each exoplanet will have its own orbital path in its own plane. For e.g. in our Solar system, all the planets have their own paths.

Earth's rotation or clouds blocking the view are also not accepted as there are space telescopes used to track stars. Even if the space telescopes are blocked when it is directly behind the Earth during its orbital, it is only for a short duration of time.

(g) One light-year = speed of light × one year = $3.0 \times 10^8 \times 365 \times 24 \times 3600$ B1
$= 9.46 \times 10^{15} = 9.5 \times 10^{15}$ m

(h) **(i)** Rayleigh criterion states that two images are just resolved when the central maximum of **the diffraction pattern** of one image falls on the first minimum of the **diffraction pattern of the other image**. A1 M1

Note!!! The answer provided is slightly different from the notes. Based on examiners comments, it is better to mention the diffraction pattern as shown above.

Do note that in this Rayleigh criterion, we are referring to **two** images and not one.

(ii)

$$S = r\theta$$

$$7.06 \times 10 = \left(9.46 \times 10^{15} \times 159\right) \times \theta$$ M1

$$\theta = 4.69 \times 10^{-9} \text{ rad}$$ A1

OR

$$\tan\frac{\theta}{2} = \frac{7.06 \times 10^9 / 2}{9.46 \times 10^{15} \times 159}$$

$$\theta = 4.69 \times 10^{-9} \text{ rad}$$

The question requires students to express answer in radians. Remember to switch calculator to radian mode!

(iii) Using Rayleigh's criterion,

$$\theta_{\text{min}} = \frac{\lambda}{b} = \left(\frac{14 \times 10^{-6}}{6.5}\right)$$ M1

$$= 2.154 \times 10^{-6} \text{ rad}$$ A1

Since θ is smaller than θ_{min}, the telescope will not be able to distinguish Osiris from the star. A1