ASSESSMENT REPORT

PHY415115 PHYSICS

The paper was well received and appears to have been set at the correct standard and of an appropriate length. This observation is supported by fact that the cutoffs for A, B and C were set in the regions of 32, 23 and 13.

A new observation this year was the high frequency of students correctly substituting into the correct equation but failing to obtain the correct answer due to misusing their calculator.

PART 1 – CRITERION 5

Question 1

(a) Generally well answered by students. A number of students found the force down the plane (1.85 N) after finding $F_R$, but did not go on to subtract it from the 3 N force up the plane to find the friction force. A number of students who calculated the correct answer did not give a direction correctly i.e. ‘down the slope’ or ‘down the plane’.

(b) Well answered by many. The unit could be joules or watts. Some students incorrectly tried to link energy with direction (i.e. used ‘cos’)

Question 2

(a) (i) Only two forces are required—tension and $F_R$ any additional vectors lost half a mark.

(ii) Generally well answered, although leaving direction (forward or left) off was common. A number of students correctly worked out the answer using forces, which took longer than an acceleration calculation.

(b) (i) Two vectors only are required. Some ‘error carried forward’ from part (a) (i) (i.e. the same incorrect vector used again here) meant more students were awarded full marks for this question than in part (a) (i).

(ii) Well answered, although some students did not convert the speed to m s$^{-1}$.

Question 3

(a) Either $F = Gm_1m_2/r^2$ or $F \propto 1/r^2$ were the only answers accepted.

(b) Only $1/r^2$ values were accepted here.

c) Students obtained marks for drawing and labelling a graph of whatever values they used, correct or incorrect, from the data table (3b) at the top of the page. ECF was applied when necessary.

(d) Reasonably well answered, but for full marks the gradient had to be used to calculate the constant. Again, ECF was applied. Where a single point, rather than the gradient, was used from an incorrect graph, a maximum of 1 mark was awarded. Most students used the correct units for Newton’s Law of Universal Gravitation.
Question 4

(a) Poorly done as most students did not apply a vector subtraction of final momentum – initial momentum. Unless the vector triangle was drawn approximately to scale, a maximum of 1 mark was awarded. Strong advice is to write the equation before drawing the vector diagram.

(b) A well-answered question. Most recognised the need to use Pythagoras’ Theorem. Too many students lost half a mark for not realising it was a ‘show that’ question and required the answer to 3 decimal places. A number of students incorrectly divided 10 km s\(^{-1}\) and 20 km s\(^{-1}\) by 3.6.

(c) This was generally done well, although some students attempted to use orbital motion equations rather than recognising that the change in momentum from part (b) was caused by a force applied over a time.

(d) Many students did not recognise that this was a collision between the probe and Jupiter, and thus the change in momentum of Jupiter is equal in magnitude to the change in momentum of the probe. This was a straightforward question for those who recognised this. Many thought Jupiter did not change momentum at all during this interaction.

(e) Part marks were awarded for recognising that this would have little or no impact on Jupiter’s orbits, explaining this in terms of the relative magnitudes of the two masses or gravitational forces. The best answers calculated the change in velocity of Jupiter using \(\Delta v = \Delta p/m\) or qualitatively explained the impact using the relevant equation. Marks were also awarded for explanations that discussed the impact of the change in velocity on the orbital radius and/or period.

(f) For full marks, students needed to describe passing the planet so that the orbital motion opposed the final direction of the probe, and the best answers used diagrams to show this. Part marks were awarded for answers that described using the gravitational attraction of the planet to oppose the motion, although this is not technically correct. Part marks were also awarded for using atmospheric drag.

Question 5

Generally well done, although this question highlighted that many students cannot use their calculator to successfully solve complex calculations; this was especially true for students who attempted to solve this problem using the two equations for centripetal acceleration rather than simplifying the equation to \(v = 2\pi r/T\). This highlighted the importance of writing equations out in full followed by writing out the equations with values substituted in; students who did this benefitted with more part marks when their final answer was incorrect than those who did not show working fully.

Other common errors were using the radius instead of the circumference of a circle when calculating the speed and not converting from m s\(^{-1}\) to km s\(^{-1}\) or doing this conversion incorrectly.

Question 6

(a) This question was generally done well. Common errors included not converting the velocity to m s\(^{-1}\), not finding the components of motion correctly, or not multiplying the time to the top by two to find the total flight time.

(b) Done well by most students.

(c) Generally done well. For the full mark students needed to find the time of flight on the Moon and divide this by the time from part (a), providing the answer to three significant figures as is standard in ‘show that’ questions. Part marks were awarded if accelerations were used instead of time and no link to time provided.
(d) Done well. Some students calculated the distance on the Moon but did not include a comparison to the distance on Earth; this was required for full marks.

PART 2 – CRITERION 6

Question 7

(a) Many candidates failed to address the question that specifically related to the lifting of the paper. The charged rod induces a separation of charge in the paper; the paper itself does not have an excess of charge (or net charge), as many candidates claimed. It was expected that candidates describe how the separation of charge in the paper can result in the paper being lifted.

(b) Many candidates did not address the question here that related to no electric field being present inside the cage. A common response was to describe why the outside of the cage conducts charge as opposed to the inside; this response did not gain any marks. Students who included a diagram in their response answered this question well.

Question 8

(a) Most candidates used the correct formula here; however, overall use of a vector addition diagram to solve this question was poor. Candidates need to be aware that the inclusion of a vector diagram is expected when solving vector problems in two dimensions.

(b) Well done.

(c) Most candidates identified the dipole field shape. Some correctly showed the stronger field close to the -4 nC charge by having more field lines incident on this charge as opposed to leaving the +2 nC charge. Only a few students correctly drew the asymmetry of the field caused by having two charges of different magnitude.

Question 9

(a) Well done.

(b) The calculation here was well done. However, a vector addition diagram should have been included to demonstrate a good understanding of the physics involved.

(c) Candidates found correctly describing the angle difficult. A correct vector diagram was required here to be successful.

Question 10

(a) This was well done by a majority of candidates. The most common error was a failure to correctly account for the angle between the field lines and velocity.

(b) This was surprisingly poorly answered. Many candidates gave an incorrect answer with no justification, meaning that no marks could be awarded. Amongst those who justified an incorrect answer, the most common error was interpreting the plane’s velocity as the ‘force’ component of the right hand rule.
(c) Very few candidates achieved full marks for this question. Full marks required acknowledgement that a circuit is required in order for current to flow, and that the circuit must be either isolated from the magnetic field or held still relative to the plane. Part marks were given for answers that addressed the low magnitude of the voltage, or its inherent variability.

**Question 11**

Few candidates achieved full marks for this question.

(a) Most were able to calculate a reasonable slope for the given graph, but many failed to convert grams to kilograms and/or convert mass to newtons.

(b) Most candidates answered this question well, once error carried forward (ECF) was applied.

(c) A majority of candidates correctly identified that the slope of the graph would decrease, but many neglected to indicate a reason or provide a quantitative measure of the effect.

**Question 12**

(a) Overall, this part was not well done. Many candidates appeared to have been distracted by the mention of the magnetic flux density.

(b) This part was well done by a majority of candidates using the given value from part (a).

(c) This part was well prepared by a majority of candidates, but poorly executed on the calculator. A surprisingly large number of candidates listed the correct values but entered 1.5 instead of 11.5 on their calculators for the flux density.

(d) This part confused many candidates, who tried to apply the wave equation and/or de Broglie’s electron wavelength calculation. For those who correctly identified an orbit situation, many stopped at calculating the period of orbit and failed to convert the period to a frequency.

**PART 3 – CRITERION 7**

**Question 13**

Part (a) was well done but part (b) was disastrous, with an average mark of 1/4. It appeared as though the teaching of this aspect of the reflection of pulses was not done or done incorrectly. The evidence for this was that there were a lot of similar answers that were just wrong. Most of the responses that were on the right track were incomplete. The inclusion of gravity was a common error.

**Question 14**

Very well answered. 8/8 was the most common mark.

**Question 15**

Parts (a) and (b)(i) were well done. In part (b)(ii) it was obvious that the relationship between the incident angle, the critical angle and total internal reflection was not understood by far too many candidates. A common incorrect statement was that the angles had to be the same for total internal reflection to occur.
Parts (c) and (d) were well done. Both were considered to be ambiguous; two answers were accepted for each part.

**Question 16**

(a) Most candidates completed this correctly.

(b) Many candidates correctly found three complete waves for the longer dimension and two waves for the shorter. Some then incorrectly stated that 18 patterns are formed rather than 3, 3, 2.

(c) Not well done, with many not able to translate the number of waves into a pattern across the microwave oven.

(d) There was very little mention of the nodal and antinodal areas that leads to differences in heating within the cavity. The rotating plate provides a more uniform heating.

(e) A large number of candidates recognised that if the energy is not absorbed, then a buildup could occur, leading to feedback into the oven.

**Question 17**

(a) Well done, with most recognising that monochromatic means one wavelength.

(b) Few connected ‘coherent’ with phase.

(c) Poorly done. Most described the pattern and did not answer the question. Very few mentioned path difference to the screen.

**Question 18**

(a) Either well done or not understood at all.

(b) About a third of candidates related the path difference to a wavelength then carried out a correct calculation.

**PART 4 – CRITERION 8**

**Question 19**

Many students struggled with this question, particularly in part (b) with very few obtaining full marks.

(a) (i) Well done. Most students correctly identified the purpose of the filter. The most common errors were to assume that it was a velocity filter or a polarisation filter.

(ii) Again, well done. Students who simply suggested a monochromatic source of light obtained half marks; students who specified a source such as a laser or grating obtained full marks.

(b) Poorly done. Most students did not realise the central wire was negatively charged in order to repel the photoelectrons without sufficient kinetic energy, and hence enable maximum kinetic energy to be determined.

(c) Well done. The most common error was to omit the units.
Question 20

This question was well done by most students.

(a) Moderately well answered. Clearly, some students believe that planets or other objects obscure the sun’s rays. Provided they also noted the drop in intensity of the sun’s rays with distance, they were not penalised.

(b) Well done. The main source of error was in not converting from MeV to eV before calculating the energy in joules.

(c) Moderately well done.

(d) Well done by most students.

(e) Well done. The main error was to not include the factor of 0.693 when calculating λ.

(f) Well done. The main error was to not convert from grams to kilograms, leading to answers that were out by a factor of 1000.

Question 21

(a) A large number of students struggled with this routine question. Many converted the mass of the entire iron atom to energy, rather than finding the difference between the mass of the iron atom and the mass of its components. Another common error was to assume that the mass of components was 56 u, rather than calculating it from the masses of neutrons, protons and electrons.

(b) Moderately well done. Most students recognised that their answer to part (a) needed to be divided by 56, although a significant number divided by 26 or 931.

(c) Few students achieved full marks for this part. Most could identify where on the graph fission and fusion reactions occur, but very few could explain how the binding energy relates to energy obtained in the reactions.

Question 22

Generally answered well. Most students correctly calculated the spectral line energies in part (a) and the wavelengths that these correspond to in part (b), although some failed to do all three spectral line energies. Part (c) was generally well answered, although some students struggled with using the correct Planck’s constant or did not have a clear understanding of eV. Part (d) asked students to sketch a graph using values from parts (b) and (c). Most students correctly identified and sketched the characteristic peaks, but surprisingly, many failed to realise that the answer in part (c) gave the shortest wavelength on the intensity graph.

Question 23

This question was generally answered well by students that understood to use de Broglie’s equation. Unfortunately, many students who failed to answer part (a) also struggled with part (c) and answers suggested that they did not understand that photons have momentum. In part (b) almost all students could correctly identify the region of the electromagnetic spectrum from the wavelength calculated in part (a).
Question 24

This question was generally very well answered. Some students lost marks in part (a) by failing to convert temperature to Kelvin. Part (b) was answered well by most students.
SOLUTIONS

PART I – NEWTONIAN

QUESTION 1

(a) Travelling at constant velocity so forces are balanced. Parallel to the plane,
\[ F_{\text{un}} = 0 = \text{force by string (up)} + \text{component of weight (down)} + \]
Friction \[ F_f = 3 - 0.55 \times 9.81 \times \sin 20^0 \]
\[ F_f = 3 - 1.85 \text{ N} = 1.15 \text{ N} \]
Force of friction = 1.15 N down plane

(b) In one second, block moves 0.5 m
Thus, Work Done = Force x distance = 3 x 0.5 = 1.5 J

QUESTION 2

(a) (i)

(ii) From sum of the force vectors,
\[ \tan 38^0 = \frac{F_{\text{un}}}{mg} \]
\[ F_{\text{un}} = mg \tan 38^0 = 0.02 \times 9.81 \times \tan 38^0 \]
\[ \text{Therefore } a = 9.81 \times \tan 38^0 \]
acceleration = 7.66 ms\(^{-2}\) forward
(b)  

(i) 

(ii) As the angle is still \(38^0\), the acceleration to the right will be \(7.66 \text{ ms}^{-2}\) by (a)  

(ii) \(a = \frac{v^2}{r}\)  

\(v = \frac{120}{3.6} = 33.3 \text{ ms}^{-1}\)  

therefore  

\(r = \frac{v^2}{a} = \frac{(33.3)^2}{7.66} = 145 \text{ m}\)

**QUESTION 3**

(a)  \(F_g = G \frac{M_1 M_2}{r^2}\)

(b)  

<table>
<thead>
<tr>
<th>(r) (metres)</th>
<th>0.200</th>
<th>0.250</th>
<th>0.300</th>
<th>0.350</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1/r^2) (m(^2))</td>
<td>25</td>
<td>16</td>
<td>11.1</td>
<td>8.16</td>
</tr>
<tr>
<td>(F) (Newtonx 10(^{-6}))</td>
<td>1.7</td>
<td>1.07</td>
<td>0.74</td>
<td>0.54</td>
</tr>
</tbody>
</table>

(c) 

(d) Slope of graph = \(G \frac{M_1 M_2}{r^2}\)  

From the graph, slope = \(1.65 \times 10^{-6} / 25 = 0.066 \times 10^{-6} \text{ Nm}^{-2}\)  

\(G = 0.066 \times 10^{-6}/ M_1 M_2 = 0.066 \times 10^{-6}/20 \times 50\)  

\(= 6.6 \times 10^{-11} \text{ Nm}^2 \text{ kg}^{-2}\)
QUESTION 4

(a) Using Pythagoras’ Theorem
\[ \Delta p = 8.20 \times 10^6 \sqrt{1^2 + 2^2} = 1.83 \times 10^7 \text{ kgms}^{-1} \]

(b) Using Pythagoras’ Theorem
\[ \text{Average force on Voyager} = \frac{\Delta p}{\Delta t} = 1.83 \times 10^7 / 15 \times 3600 \text{ N} = 339.6 \text{ N} \]

(c) By Conservation of Momentum, Change of momentum of Jupiter = 1.83 \times 10^7 \text{ kgms}^{-1}

(e) \begin{align*}
\Delta v \text{ of Jupiter} &= \frac{\Delta p}{m} = 1.83 \times 10^7 / 1.90 \times 10^{27} = 9.63 \times 10^{-21} \text{ ms}^{-1} \\
&\text{This is entirely negligible.}
\end{align*}

(f) If the probe passes on the leading side of the planet, the side moving forward with respect to the Sun, then the probe will slightly speed up the planet but in so doing, the probe will slow down.

QUESTION 5

(a) \begin{align*}
\nu_{av} &= \text{distance travelled / time} \\
&= 2\pi r / t = 2 \times \pi \times 1.30 \times 10^{14} / 16.1 \times 365 \times 24 \times 3600 \text{ ms}^{-1} \\
&= 1.61 \times 10^6 \text{ ms}^{-1} \\
&= 1610 \text{ kms}^{-1}
\end{align*}

(b) \begin{align*}
g &= \frac{GM}{r^2} = \frac{\nu^2}{r}, \quad M = \frac{\nu^2 r}{G} \\
&= (1.61 \times 10^6)^2 \times 1.30 \times 10^{14} / 6.67 \times 10^{-11} \\
&= 5.05 \times 10^{36} \text{ kg}
\end{align*}

(c) number of stars = total mass / mass of Sun = 5.05 \times 10^{36} / 2 \times 10^{30} = 2.52 \times 10^6 \text{ stars}

(d) An excellent candidate for a Black Hole!

QUESTION 6

(a) Converting initial speed to ms^{-1}, \nu = 140 / 3.6 = 38.9 \text{ ms}^{-1}
Vertically, vertical component of the velocity = 38.9 sin 40° = 25.0 ms⁻¹
Using \( s = ut + \frac{1}{2} at^2 \) where \( s = 0 \ a = 9.81 \text{ ms}^{-2} \) down
\[ 0 = 25t - 4.9 t^2 \text{ so } t = 0 \text{ or } t = 5.10 \text{ s} \]
time above ground is 5.10 s

(b) Using horizontal components,
\[ s = ut + \frac{1}{2} at^2 \]
\( a = 0 \), \( u = 38.9 \cos 40° = 29.8 \text{ ms}^{-1} \)
\[ = 29.8 \times 5.10 = 152 \text{ m} \]
Distance travelled on Earth is 152 m

(c) On the Moon, vertically \( a = 1.62 \text{ ms}^{-2} \) down, \( s = 0 \text{ m} \)
\[ s = ut + \frac{1}{2} at^2 \]
\[ 0 = 25t - 0.81 t^2 \]
Gives \( t = 0 \) or \( t = 30.9 \text{ s} \) - about 6 times larger

(d) Horizontally
\[ s = ut + \frac{1}{2} at^2 \]
\( a = 0 \), \( u = 38.9 \cos 40° = 29.8 \text{ ms}^{-1} \)
\[ = 29.8 \times 30.9 \text{ m} \]
\[ = 919 \text{ m} \] - about 6 times larger to distance on Earth

PART 2 — ELECTROMAGNETISM

QUESTION 7

(a)

The charge on the rod attracts the opposite charge on the paper towards it as opposite charges attract and like repel. The same charge on the paper is slightly repelled. As the forces are inversely proportional to distance squared by Coulomb’s Law, the attraction between the opposite charges is greater than the repulsion. This creates an unbalanced force on the paper so the paper can be lifted.

(b) Two possible explanations which are equivalent.
Explanation 1
At any given point within the cage, the total field within due to charge on the cage must be zero as any charged area A of the cage has a corresponding area B on the other side which will cancel out the field. The areas vary as to the square of the distance to the point which is exactly cancelled by the inverse square law of Coulomb! (See diagram)

Explanation 2

The cage is a conductor so the entire surface of the conductor must be everywhere at the same potential difference with respect to the ground. Within the cage, everywhere must therefore be at the same potential difference with respect to the ground. Taking two points in the cage, the PD between them must be zero and, as \( E = \frac{V}{d} \), the field strength must be zero.

QUESTION 8

(a)

At P, individual field strengths

\[ E_1 \text{ due to } +2 \, \text{nC} \quad E_1 = \frac{kQ_1}{r^2} = 9.00 \times 10^9 \times 2 \times 10^{-9}/(0.03)^2 = 2 \times 10^4 \, \text{NC}^{-1} \, \text{away from charge} \]

\[ E_2 \text{ due to } -4 \, \text{nC} \quad E_2 = \frac{kQ_2}{r^2} = 9.00 \times 10^9 \times 4 \times 10^{-9}/(0.03)^2 = 4 \times 10^4 \, \text{NC}^{-1} \, \text{toward charge} \]

At P, using cos rule \( E_T = 2 \times 10^4 \left( 1^2 + 2^2 - 2 \times 1 \times 2 \times \cos 60^\circ \right)^{1/2} \]

\[ = 2 \times 10^4 \times 1.732 \]

\[ = 3.46 \times 10^4 \, \text{NC}^{-1} \]

(b) Using \( F = qE \), magnitude of force on charge \( = 3.46 \times 10^4 \times 2 \times 10^{-12} \, \text{N} \]

\[ = 6.92 \times 10^{-9} \, \text{N} \]
(c)

QUESTION 9

(a) Coulomb’s Law \( F = kQ_1Q_2/r^2 \) becomes \( F = kQ^2/r^2 \) as the charges are equal sized. For \( A \) on \( B \), \( F_{AB} = 4 \times 10^{-6} = kQ^2/(0.02)^2 \) thus \( kQ^2 = 1.6 \times 10^{-9} \)

Hence, size \( F_{CB} = 1.6 \times 10^{-9}/(0.0173)^2 = 5.34 \times 10^{-6} \) N

(b)

The two forces are perpendicular to each other
Size of \( F_T = 10^{-6} \times (4^2 + 5.34^2)^{1/2} \) N
\[ = 10^{-6} \times (16 + 28.5)^{1/2} \] N
\[ = 6.67 \times 10^{-8} \] N

(c) From the diagram above, the angle \( \theta \) to the line \( AB \) is given by
\[ \tan \theta = F_{CB}/F_{AB} = 5.34/4 \]
\[ \theta = 53.2^\circ \) to the line \( AB \)

QUESTION 10

(a) \( v = 900/3.6 \text{ m/s}^{-1} = 250 \text{ m/s}^{-1} \)

Potential Difference = \( v\text{lB} \sin \theta \)
\[ = 250 \times 64.75 \times 1.90 \times 10^{-5} \times \sin 70^\circ \]
\[ = 0.289 \text{ volts} \]
(b) By a Right Hand Rule or equivalent, positive charge is driven East so the West wing becomes negative.

(c) The electronics are moving with the plane so all East – West parts of the circuits will experience a potential difference across them. Once the PD is established by the motion of the wires, the transient current stops. No permanent current will therefore be created in the circuits by the motion of the plane.

Alternatively, to create a potential difference across a load so that a current flows, the load must be stationary with respect to the ground while the wings move forward to act as a generator. This is clearly impractical!

QUESTION 11

(a) The slope in grams per amp = 0.3/5 = 0.06 grams per amp. Thus the slope in newtons per amp = 0.06 x 9.81/1000 = 5.89 x 10^{-4} \text{ NA}^{-1}

(b) 
\[
F_B = lB \sin \theta \quad \text{so} \quad B = \text{slope} / 0.02 = 5.89 \times 10^{-4} / 0.02 \quad B = 0.0295 \text{ T}
\]

(c) From the above, rotating the wire 45^0 in the horizontal plane will reduce the slope by a factor of \(\sin 45^0\) or 0.707, to 4.16 x 10^{-4} \text{ NA}^{-1}.

QUESTION 12

(a) Potential energy lost = \(E_k\) gained, qV = \(\frac{1}{2} mv^2\)
So \(v = (2qV/m)^{1/2} = 2.90 \times 10^7 \text{ ms}^{-1}\)

(b) \(F_B = qvB = 1.6 \times 10^{-19} \times 2.90 \times 10^7 \times 11.5 \times 10^{-3} \text{ N} = 5.34 \times 10^{-14} \text{ N}\)

(c) \(r = mv/qB = 9.11 \times 10^{-31} \times 2.90 \times 10^7 / 1.6 \times 10^{-19} \times 11.5 \times 10^{-3} = 0.0144 \text{ m}\)

(d) Time for one orbit = distance / speed = \(2\pi r /v = 2\pi \times 0.0144 / 2.90 \times 10^7 = 3.12 \times 10^{-9} \text{ s}\)
So, frequency = \(1/T = 3.21 \times 10^8 \text{ Hz}\)
PART 3 – WAVES

QUESTION 13

(a)

(b) (i) Free end.

The end loop rises freely on the pole then the tension force in the string pulls back to its original position generating the reflected pulse remaining upright.

(ii) Fixed end.

The string pulls up on the fixed end. By Newton’s Third Law, an equal but opposite force acts down on the string leading to the inverted reflection.

QUESTION 14

(a)

(b) The wavelength of 32 Hz at this temperature, $\lambda = \frac{v}{f}$

$\lambda = \frac{v}{f}$

$= \frac{339}{32}$

$= 10.6$ m

At the fundamental frequency, the pipe length is half a wavelength so the pipe length = 5.3m.
(c) The new velocity = 331.3 + 20 x 0.606 = 343.4 ms$^{-1}$
Hence new frequency = 342.4 /10.6 = 32.4 Hz

(d) The raising of the temperature would raise the frequency of the pipes putting them out of tune with each other! This could lead to discordant notes and unwanted beating.

QUESTION 15

(a) Snell's Law \[ n_{\text{air}} \sin \theta_{\text{air}} = n_{\text{water}} \sin \theta_{\text{water}} \] where $\theta_{\text{water}}$ = angle of refraction
\[ 1 \times \sin 60^\circ = 1.331 \times \sin \theta_{\text{water}} \]
Therefore \[ \sin \theta_{\text{water}} = 0.8660 / 1.331 \]
\[ = 0.6510 \]
Angle of refraction = 40.6$^\circ$

(b) (i) Critical angle $\theta_c$ \[ \sin \theta_c = 1/1.331 = 0.7513 \]
\[ \theta_c = 48.7^\circ \]
(ii) The angle of incidence at B = 40.6$^\circ$ as the triangle formed by the centre and AB is isosceles. This is less than the critical angle so the light is NOT fully internally reflected.

(c) As the angle of incidence is 40.6$^\circ$, the angle of departure will be 60$^\circ$. As written, the answer can also be given as 40.6$^\circ$.

(d) [Diagram]

QUESTION 16

(a) Wavelength = speed of light / frequency
\[ \lambda = c / f = 3.00 \times 10^8 / 2.45 \times 10^9 \]
\[ = 0.122 \text{ m} = 12.2 \text{ cm} \]
(b) Number of waves across = 36.7 / 12.2 = 3 complete waves, Number of waves vertically = 24.5 / 12.2 = 2 complete waves

(c)

(d) Food in a nodal area will not be heated but in an antinodal area it will possibly be over heated. The rotating glass plate is to ensure all the food passes through heating areas.

(e) If the energy associated with the wave is not absorbed then the intensity of the standing waves will increase (resonance) and get back into the generator (the magnetron). This can lead to unwanted currents in the magnetron possibly causing it to fail.

**QUESTION 17**

(a) “Monochromatic” means one wavelength or colour when applied to electromagnetic radiation.

(b) “Coherent” light means the wave fronts are at the same phase across the entire wavefront. This leads to the emitted wavefront from the whole width of the slit to be in phase.

(c)

Consider monochromatic, coherent light from the either side of the slit onto the screen. There is a path difference between the two rays as seen in the diagram above. When these combine they will interfere and, if the path difference is the correct value, nodes and antinodes can be produced.
Labelling the points P and Q, then PB’Q is the Path Difference.

\[ \frac{PB'}{BB'} = \sin \theta = \frac{PB'}{d} \text{ so } PB' = d \sin \theta \]

Thus, Total Path Difference = 2d \sin \theta

(b) Assuming the bright spot refers to the first antinode then

Total Path Difference = 2d \sin \theta = \text{one wavelength} = \lambda.

So \[ d = \lambda / 2 \sin \theta = 1.00 \times 10^{-10} / 2 \sin 4.48^\circ = 6.40 \times 10^{-10} \text{ m} \]

PART 4 TWENTIETH CENTURY

QUESTION 19

(a) (i) Purpose is to provide monochromatic light on the metal of the phototube.

(ii) Use spectral lines of different elements from a spectral lamp.

(b) The negative terminal is connected to the central wire to REPEL photoelectrons emitted from the metal plate when illuminated by the different wavelengths. If the value of the potential difference is known, the maximum kinetic energy of the photoelectrons can be measured.

(c) When the “Stopping Voltage” is reached, the microammeter will just read zero.

QUESTION 20

(a) When travelling so far out into the Solar System, sunlight is too weak to provide the power needed for the electrical systems.

(b) Mass difference = mass of parent isotope – mass of products

\[ = 238.049553 - (234.040950 + 4.001506) \text{ u} \]

\[ = 0.007097 \text{ u} \]

Energy in MeV per decay = 6.607 MeV

Energy in J per decay = \[ 1.057 \times 10^{12} \text{ J} \]
(c) Total power x efficiency = 470 W
   Thus, Total power = 470 / 0.05 W = 9400 W

(d) In one second, n x energy release for one reaction = 9400 J
   n = 9400 / 1.057 x 10^{-12}
   = 8.89 x 10^{15} decays = activity of isotope

(e) A = \lambda N \quad \text{where } \lambda = \text{decay constant} = 0.693 / T \text{T}_{1/2}
   N = A x T_{1/2} / \lambda
   = 8.89 x 10^{15} x 87.7 x 365 x 24 x 3600 / 0.693
   = 3.55 x 10^{25} \text{ atoms}

(f) number of moles, n = N / N_A = m / M \quad m = \text{mass}, M = \text{Molar mass}
   Mass of Pu-238 isotope needed
   m = N x M / N_A = 3.55 x 10^{25} x 238 / 6.02 x 10^{23}
   = 13.8 \text{ kg}

**QUESTION 2.1**

(a) Mass defect of Fe-56 = mass of components of atom – mass of atom
   = ( 26 x m_p + 26 x m_e + 30 x m_n ) – 55.9349375 u
   (sometimes mass of electrons are ignored)
   = ( 26 x 1.007276 + 26 x 0.000549 + 30 x 1.008665 ) – 55.9349375 u
   = ( 26.189176 + 0.014274 + 30.259955 ) – 55.9349375 u
   = ( 56.449126 + 0.014274) – 55.9349375 \ u
   = 0.5142 u if electrons are ignored, 0.528 u if electrons are included
   
   Hence Binding Energy = 478.5 MeV if electrons are ignored and 492 MeV if electrons are included.

(b) BE /nucleon = 8.77 MeV per nucleon if electrons included, 8.55 MeV per nucleon if ignored

(c) All elements emit energy when the component protons and neutrons are assembled to make nuclei. After Fe-56, however, more energy is required to assemble heavier elements from Fe-56 nuclei and succeeding nuclei. Thus if heavy nuclei are split back towards Fe-56 there is a net energy emission. This is nuclear fission. For elements lighter than Fe-56, however, assembly of nuclei still gives a net emission though this is greatest for the very light elements. This process is nuclear fusion and takes place in stars.
QUESTION 22

(a) Three possible transitions are

\[ \begin{align*}
\text{n = 3 to 1} & : \Delta E = 69.5 - 2.5 = 67.0 \text{ keV} \\
\text{n = 2 to 1} & : \Delta E = 69.5 - 10.2 = 59.3 \text{ keV} \\
\text{n = 3 to 2} & : \Delta E = 10.2 - 2.5 = 7.7 \text{ keV}
\end{align*} \]

(b) \( E = \frac{hc}{\lambda} \), thus \( \lambda = \frac{hc}{E} \)

\[ \begin{align*}
\text{n = 3 to 1, } \lambda_{31} = \frac{hc}{E} & = 4.14 \times 10^{-15} \times 3.00 \times 10^8 / 67 \times 10^3 = 1.85 \times 10^{-11} \text{ m} \\
\text{n = 2 to 1, } \lambda_{21} = \frac{hc}{E} & = 4.14 \times 10^{-15} \times 3.00 \times 10^8 / 59.3 \times 10^3 = 2.09 \times 10^{-11} \text{ m} \\
\text{n = 3 to 2, } \lambda_{32} = \frac{hc}{E} & = 4.14 \times 10^{-15} \times 3.00 \times 10^8 / 7.7 \times 10^3 = 1.61 \times 10^{-10} \text{ m}
\end{align*} \]

(c) \( E_p \) lost by electron = maximum photon energy = 100 keV

\[ E = \frac{hc}{\lambda}, \text{ so shortest wavelength } \lambda_{\text{min}} = \frac{hc}{E} = 4.14 \times 10^{-15} \times 3.00 \times 10^8 / 100 \times 10^3 = 1.24 \times 10^{-11} \text{ m} \]

(d)

QUESTION 23

(a) Using de Broglie’s equation \( \lambda = \frac{h}{mv} \)

\[ = 6.63 \times 10^{-34} / 9.11 \times 10^{-31} \times 3 \times 10^4 = 2.42 \times 10^{-8} \text{ m} \]

(b) From the spectrum chart, the boundary of ultraviolet and X rays.

(c) They will have identical momenta as the generalised formula of de Broglie by Compton is \( \lambda = \frac{h}{p} \) which is true for all objects.
QUESTION 24

(a) Using the Wien Displacement Law \( \lambda_p T = 2.90 \times 10^{-3} \text{ mK} \),
\[ \lambda_p = \frac{2.90 \times 10^{-3}}{37 + 273} \]
\[ = 9.35 \times 10^{-6} \text{ m or } 9.35 \mu \text{m} \]

(b) The infrared detection will work best under cool conditions rather than very hot. Night time, or at sea, but not in hot inland day conditions. The reason being that for best contrast, the temperature of the living object needs to be significantly higher than the surrounding temperature. Then it is brighter than the surrounding objects at 9.35 \( \mu \text{m} \) and can be seen far more easily.