## 1. Generic Matrix

| Element of examination | Competence | Weight in % | Evaluation/Marking | Weight in marks |
|---|---|---|---|---|
| Fields | Knowledge and Comprehension | ± 37 % | Paper-specific Marking Scheme | ± 11 |
| | Application | ± 37 % | | ± 11 |
| | Analysis and Evaluation | ± 16 % | | ± 5 |
| | Written Communication | ± 10 % | | ± 3 |
| | | 100 % | | 30 |
| Waves | Knowledge and Comprehension | ± 37 % | Paper-specific Marking Scheme | ± 11 |
| | Application | ± 37 % | | ± 11 |
| | Analysis and Evaluation | ± 16 % | | ± 5 |
| | Written Communication | ± 10 % | | ± 3 |
| | | 100 % | | 30 |
| Atomic Physics | Knowledge and Comprehension | ± 35 % | Paper-specific Marking Scheme | ± 7 |
| | Application | ± 35 % | | ± 7 |
| | Analysis and Evaluation | ± 20 % | | ± 4 |
| | Written Communication | ± 10 % | | ± 2 |
| | | 100 % | | 20 |
| Nuclear Physics | Knowledge and Comprehension | ± 35 % | Paper-specific Marking Scheme | ± 7 |
| | Application | ± 35 % | | ± 7 |
| | Analysis and Evaluation | ± 20 % | | ± 4 |
| | Written Communication | ± 10 % | | ± 2 |
| | | 100 % | | 20 |
| | | | | |
| Total Exam | | | | 100 |

In each section a deviation of up to 5% will be tolerated as long as the total number of marks (30 points respectively 20 points) is respected for each question.

## 2. Paper-specific Matrix

| Element of examination | Competence | Weight in % | Evaluation/Marking | Weight in marks |
|---|---|---|---|---|
| Fields | Knowledge and Comprehension | 35.0 % | Paper-specific Marking Scheme<br><br>see part 4 | 10.5 |
| | Application | 38.3 % | | 11.5 |
| | Analysis and Evaluation | 18.3 % | | 5.5 |
| | Written Communication | 8.3 % | | 2.5 |
| | | 100 % | | 30 |
| Waves | Knowledge and Comprehension | 40.0 % | Paper-specific Marking Scheme<br><br>see part 4 | 12.0 |
| | Application | 33.3 % | | 10.0 |
| | Analysis and Evaluation | 16.7 % | | 5.0 |
| | Written Communication | 10.0 % | | 3.0 |
| | | 100 % | | 30 |
| Atomic Physics | Knowledge and Comprehension | 32.5 % | Paper-specific Marking Scheme<br><br>see part 4 | 6.5 |
| | Application | 37.5 % | | 7.5 |
| | Analysis and Evaluation | 20.0 % | | 4.0 |
| | Written Communication | 10.0 % | | 2.0 |
| | | 100 % | | 20 |
| Nuclear Physics | Knowledge and Comprehension | 35.0 % | Paper-specific Marking Scheme<br><br>see part 4 | 7.0 |
| | Application | 35.0 % | | 7.0 |
| | Analysis and Evaluation | 17.5 % | | 3.5 |
| | Written Communication | 12.5 % | | 2.5 |
| | | 100 % | | 20 |
| | | | | |
| Total Exam | | | | 100 |

## 3. Sample BAC Written Examination

| Question 1 | | |
|---|---|---|
| **Part A** | **Page 1/4** | **Marks** |

TRAPPIST-1 is an ultra-cool red dwarf star that is slightly larger, but has a much greater mass than the planet Jupiter. On February 22nd, 2018, astronomers announced that the planetary system of this star is composed of seven planets.

In this question, assume that all planets are moving in circular orbits.

| The TRAPPIST-1 planetary system | | | |
|---|---|---|---|
| Planet | Mass (Earth masses) | Orbital radius ($10^6$ km) | Orbital period (Earth days) |
| b | 1.02 | 1.73 | 1.51 |
| c | 1.16 | 2.37 | 2.42 |
| d | 0.30 | 3.33 | 4.05 |
| e | 0.77 | 4.38 | 6.10 |
| f | 0.93 | 5.76 | 9.21 |
| g | 1.14 | 7.01 | 12.35 |
| h | 0.33 | 9.27 | 18.77 |
| *Source: Wikipedia EN, Jan 18th, 2019* | | | |

**a)** Kepler's 3rd law states that for planetary orbits $\frac{T^2}{r^3}$ is a constant, where $T$ is the orbital period and $r$ the orbital radius.

Verify Kepler's 3rd law using data for 2 planets from the table above. — 3 marks

**b)** Show that the orbital velocity of planet "e" is equal to $v_e = 5.22 \times 10^4$ m s$^{-1}$. — 3 marks

**c)** For any two planets that are orbiting at a distance $r_1$ and $r_2$ from a star, the ratio of their orbital velocities $v_1$ and $v_2$ is given by

$$\frac{v_1}{v_2} = \sqrt{\frac{r_2}{r_1}}\ .$$

Derive this expression. — 3 marks

**d)** One of the planets of TRAPPIST-1 has an orbital velocity of $4.13 \times 10^4$ m s$^{-1}$.

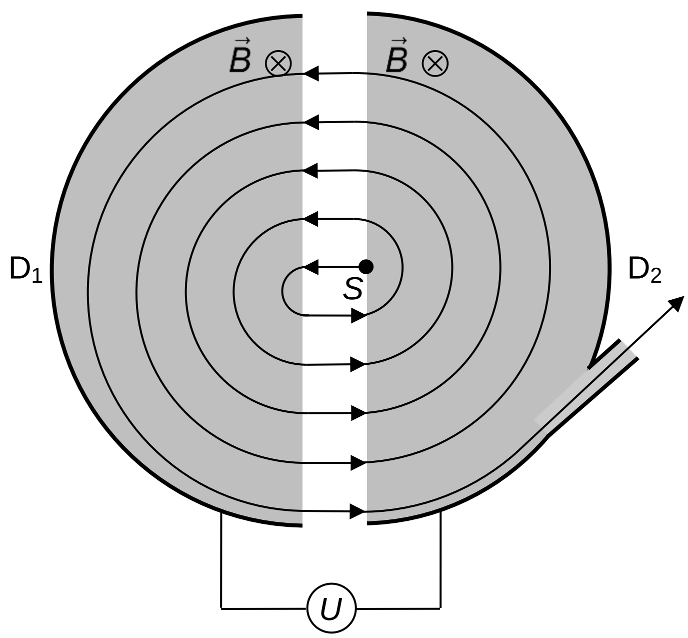
Which planet is it? — 3 marks

## 3. Sample BAC Written Examination

| Question 1 | | |
|---|---|---|
| **Part A** | **Page 2/4** | **Marks** |
| **e)** **i.** Show that the total mechanical energy of a planet orbiting around a star is given by $$E_{tot} = -G\frac{m\,M}{2\,r}\ ,$$ where $m$ is the mass of the planet, $M$ the mass of the star, and $r$ the distance between the planet and the star. | | 3 marks |
| **ii.** The mass of TRAPPIST-1 is $1.77\times10^{29}$ kg. Calculate the total mechanical energy of planet "e". | | 1 mark |

| Part A | |
|---|---|
| **Given**: | |
| mass of the Earth | $m_E = 5.97\times10^{24}$ kg |
| universal gravitational constant | $G = 6.67\times10^{-11}$ m$^3$ kg$^{-1}$ s$^{-2}$ |

### 3. Sample BAC Written Examination

| Question 1 | | |
|---|---|---|
| **Part B** | **Page 3/4** | **Marks** |
| A cyclotron is a particle accelerator. It consists of two hollow half-cylinders $D_1$ and $D_2$, known as Dees, separated by a narrow gap (see figure below).<br>In an experiment, protons are emitted with negligible initial velocity by the source *S*.<br><br>In the gap between the Dees, the protons are accelerated by a potential difference *U*. The potential difference changes sign after every passage of the protons through the gap. The absolute value of this potential difference is $U = 1.00 \times 10^4$ V when a proton crosses the gap.<br><br>A uniform magnetic field $\vec{B}$ with *B* = 1.00 T is present inside the Dees, with a direction parallel to the axis of the half-cylinders.<br><br>The subsequent trajectory of the protons in each Dee is circular. The radius increases after each crossing through the gap.<br><br> | | |

## 3. Sample BAC Written Examination

| **Question 1** | | |
|---|---|---|
| **Part B** | **Page 4/4** | **Marks** |
| **a)** A proton enters a Dee with speed $v$. | | |
| **i.** Show that the radius $R$ of its trajectory is given by: $R = \frac{m_p v}{e B}$ | | 3 marks |
| **ii.** Show, by deriving a formula for the time $\Delta t$ spent in a Dee, that this time is independent of speed. | | 2 marks |
| **b) i.** Show that the increase in kinetic energy of a proton for each gap crossing is $1.00 \times 10^4$ eV. | | 2 marks |
| **ii.** Calculate the radius $R_1$ of the first circular trajectory. | | 3 marks |
| **c)** A proton accelerated by the cyclotron has its maximum energy as it exits the Dee after its last revolution. The radius of the trajectory at the exit from the cyclotron is $R_{max} = 0.289\,\text{m}$. | | |
| **i.** Show that the maximum kinetic energy of this proton is $E_{max} = 4.00$ MeV. | | 3 marks |
| **ii.** Calculate the number of revolutions necessary for this proton to acquire the maximum kinetic energy. | | 1 mark |

| **Part B** | |
|---|---|
| **Given:** | |
| elementary charge | $e = 1.60 \times 10^{-19}$ C |
| mass of the proton | $m_p = 1.67 \times 10^{-27}$ kg |

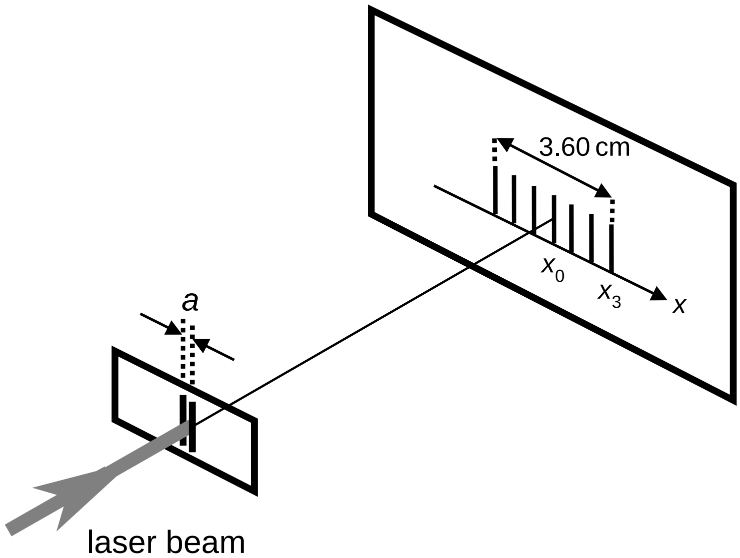
## 3. Sample BAC Written Examination

| Question 2 | | |
|---|---|---|
| **Part A** | **Page 1/3** | **Marks** |
| The lengths of organ pipes vary between several metres and a few centimetres. Some of the pipes are open at both ends (“open pipes”) and others are open at one end and closed at the other end (“closed pipes”).<br>The human ear can hear sounds with frequencies between 20 Hz and 16 000 Hz. | | |
| **a)** **i.** For both types of pipes, sketch diagrams of the fundamental wave and the first overtone, indicating the position of the nodes. | | 4 marks |
| **ii.** Calculate the lengths of both types of pipes which produce a fundamental note of 20 Hz. | | 3 marks |
| **iii.** For two pipes with the same length, one “open” and one “closed”, calculate the ratio of the frequencies of their first overtones. | | 2 marks |
| **b)** Consider a note of frequency 440 Hz. If you go down or up one octave the frequency either halves or doubles respectively. | | |
| **i.** Calculate the frequency of a note, which is four octaves below 440 Hz, and decide whether the human ear can still hear that note. | | 2 marks |
| **ii.** The frequency of the highest note several octaves above 440 Hz which we can still hear is 14080 Hz. | | |
| 1. Calculate how many octaves it lies above the 440 Hz. | | 1 mark |
| 2. The shortest pipe in an organ is 6.14 mm long. | | |
| Decide by using a calculation whether it is an “open pipe” or a “closed pipe”, knowing that its fundamental frequency is 14080 Hz. | | 3 marks |

| Part A | |
|---|---|
| **<u>Given</u>**: | |
| speed of sound in air | $v_{sound} = 346\,\mathrm{m\,s^{-1}}$ |

### 3. Sample BAC Written Examination

**Question 2**

| **Part B** | **Page 2/3** | **Marks** |
|---|---|---|
| **a)** Students perform Young's experiment using laser light with wavelength $\lambda$. The light is incident on a double slit with slit separation *a*. An interference pattern is observed on a screen located at the distance *L* from the double slit. The screen is parallel to the plane of the double slits. | | |
| **i.** Show that the positions of the maxima on the screen is given by: $x_k = k\,\dfrac{L\,\lambda}{a}$ , where $k = 0, \pm 1, \pm 2, ...$ State the approximations used. | | 4 marks |
| **ii.** Knowing that the distance between the two 3rd order maxima on the screen is 3.60 cm, $L = 4.00$ m and $\lambda = 546$ nm, calculate the slit separation *a* (see figure below).   | | 2 marks |
| **b)** Using a double slit with $a = 3.64 \times 10^{-4}$ m, the students replace the laser with a source, which emits red light ($\lambda_1 = 672$ nm) and green light ($\lambda_2$). On the screen there is an overlap of interference patterns. A maximum for green overlaps with the third order maximum for red. Determine the wavelength $\lambda_2$ of the green light and the order of the green maximum overlapping the red maximum. | | 4 marks |

### 3. Sample BAC Written Examination

| Question 2 | | |
|---|---|---|
| **Part B** | **Page 3/3** | **Marks** |
| **c)** Students use another laser and replace the double slit with a diffraction grating with 4000 lines per centimetre. The distance $L = 4.00$ m remains unchanged. The first maximum is observed at a distance 0.871 m from the central maximum on the screen. The diffraction grating formula is <br> $k\,\lambda = d\sin(\theta_k)$ . | | |
| **i.** Explain the meaning of $d$ and $\theta_k$ in this formula. | | 1 mark |
| **ii.** Show that the wavelength of the laser light is 532 nm. | | 4 marks |

| Part B | |
|---|---|
| **<u>Given</u>:** | |
| wavelength of green light | $500\text{ nm} \leq \lambda \leq 560\text{ nm}$ |
| speed of light in a vacuum | $c = 3.00 \times 10^8\ \text{m s}^{-1}$ |

## 3. Sample BAC Written Examination

### Question 3

| | Page 1/1 | Marks |
|---|---|---|
| **a)** The equation below is Einstein's equation describing the photoelectric effect when a photocell is illuminated by light of frequency $f$ <br> $hf = W_0 + E_{kin}$. | | |
| **i.** Explain what is meant by the three terms $hf$, $W_0$ and $E_{kin}$. | | 3 marks |
| **ii.** Monochromatic light of wavelength 486 nm is used to illuminate the photocell. The photocathode is coated with a thin layer of caesium with a work function of 2.08 eV and has a surface area of 100 mm$^2$. <br> The intensity of the light which is incident on the cathode of the photoelectric cell is $0.100\ \text{W m}^{-2}$. | | |
| **1.** Show that the energy of a single photon of this light is $4.09 \times 10^{-19}\ \text{J}$. | | 3 marks |
| **2.** Calculate the maximum kinetic energy of a photoelectron. | | 2 marks |
| **3.** Show that the number of photons incident on the surface of the photocathode equals $2.44 \times 10^{13}$ per second. | | 4 marks |
| **4.** Calculate the maximum photocurrent assuming that 4 % of the photons result in photoelectron emission. | | 4 marks |
| **b)** In the hydrogen atom spectrum the wavelengths can be sorted into series like the Balmer series. <br> The photons of the Balmer series are emitted when electrons make transitions from states with the quantum number $n \geq 3$ to $n = 2$. The table below shows the values of the first five energy levels $E_n$ for the hydrogen atom. | | |

| Quantum number $n$ | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| $E_n$ / eV | –13.6 | –3.40 | –1.51 | – 0.85 | – 0.54 |

One of the Balmer series transitions results in the emission of a photon with wavelength 486 nm.

Between which energy levels does this transition occur? — 4 marks

**Given:**

| | |
|---|---|
| Planck's constant | $h = 6.63 \times 10^{-34}\ \text{J s}$ |
| speed of light in a vacuum | $c = 3.00 \times 10^{8}\ \text{m s}^{-1}$ |
| elementary charge | $e = 1.60 \times 10^{-19}\ \text{C}$ |

## 3. Sample BAC Written Examination

| Question 4 | | |
|---|---|---|
| | **Page 1/2** | **Marks** |

**a)** One of the isotopes of the element technetium is $^{99}_{43}Tc$.

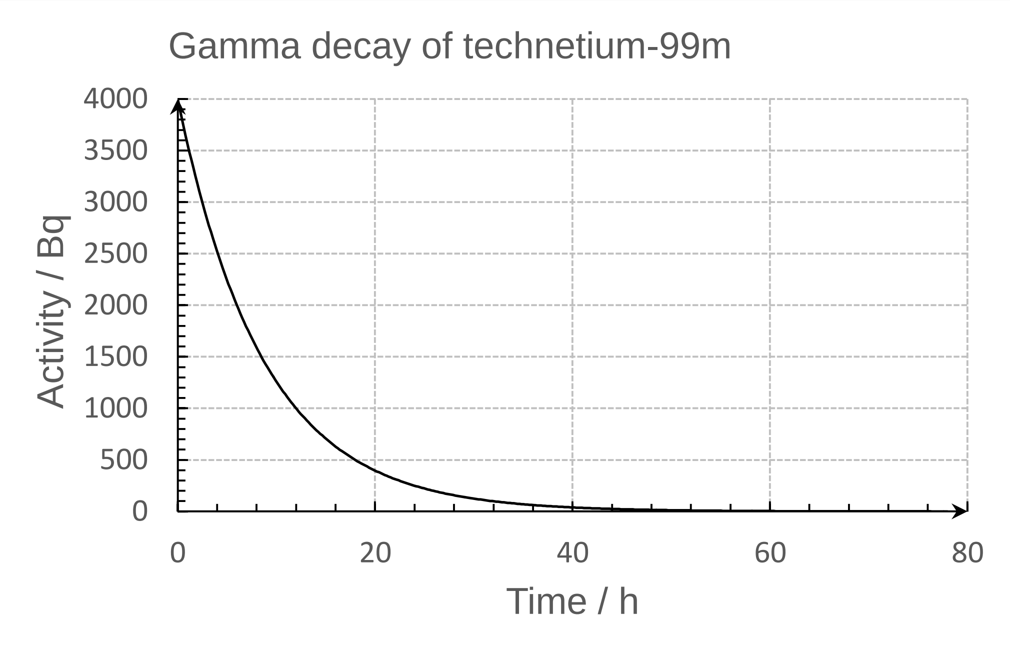
**i.** What do we mean by the term "isotope"? — 1 mark

**ii.** What is the composition of the nucleus of this isotope? — 1 mark

**iii.** $^{99}_{43}Tc$ decays into $^{99}_{44}Ru$.

Write the decay equation of $^{99}_{43}Tc$ to $^{99}_{44}Ru$ and state which type of decay it is. — 2 marks

Technetium-99m is a metastable isotope that decays to $^{99}_{43}Tc$ by emitting gamma radiation. Technetium-99m is widely used in nuclear medicine. In the graph below you can see the activity of a sample of technetium-99m:




**iv.** Explain the meaning of the term "half-life", $T_{1/2}$, for a radioactive isotope. — 1 mark

**v.** From the graph, estimate the half-life of technetium-99m. — 1 mark

**vi.** Show that $T_{1/2} = \frac{\ln(2)}{\lambda}$, where $\lambda$ is the decay constant. — 2 marks

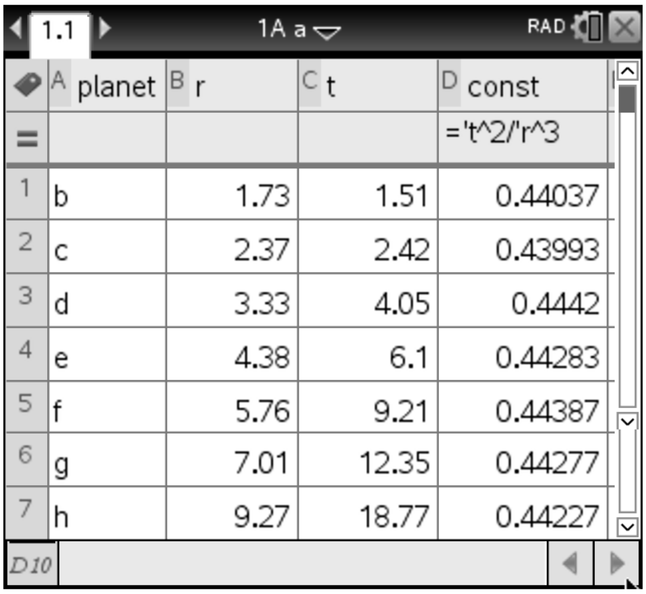
## 3. Sample BAC Written Examination

| Question 4 | | |
|---|---|---|
| | **Page 2/2** | **Marks** |
| **b)** One of the fission reactions that uranium may undergo in a nuclear reactor is: $$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{141}_{56}\text{Ba} + ^{92}_{36}\text{Kr} + 3\,^{1}_{0}\text{n}$$ | | |
| **i.** Explain how a chain reaction is produced, and the role of a moderator in a nuclear reactor. | | 4 marks |
| **ii.** Calculate the energy released by this reaction. | | 4 marks |
| **c)** In a reactor using uranium-235, a variety of fission reactions occur. The average energy released per fission is 210 MeV. | | |
| Calculate the mass of uranium-235 that undergoes fission per hour to run a 2.00 GW power plant assuming an efficiency of 33 %. | | 4 marks |

**<u>Given</u>:**

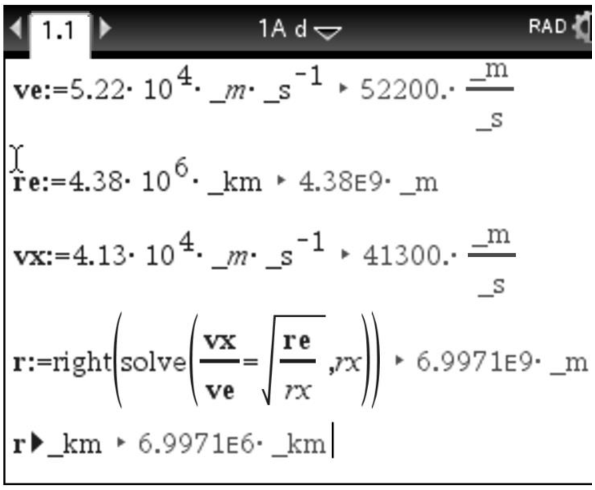
| | |
|---|---|
| atomic mass unit | $1\,\text{u} = 931.5\ \text{MeV}/c^2 = 1.66 \times 10^{-27}\ \text{kg}$ |
| speed of light in a vacuum | $c = 3.00 \times 10^{8}\ \text{m s}^{-1}$ |
| elementary charge | $e = 1.60 \times 10^{-19}\ \text{C}$ |
| mass of the neutron | $m_\text{n} = 1.008\,665\ \text{u}$ |
| atomic mass of $^{92}_{36}\text{Kr}$ | 91.926 156 u |
| atomic mass of $^{141}_{56}\text{Ba}$ | 140.914 411 u |
| atomic mass of $^{235}_{92}\text{U}$ | 235.043 930 u |

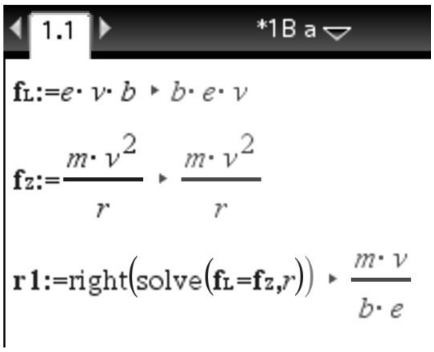
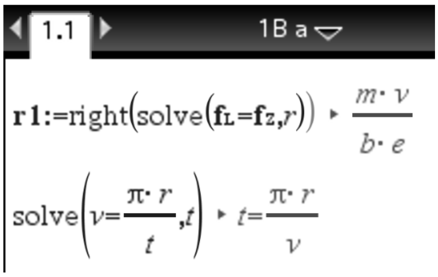
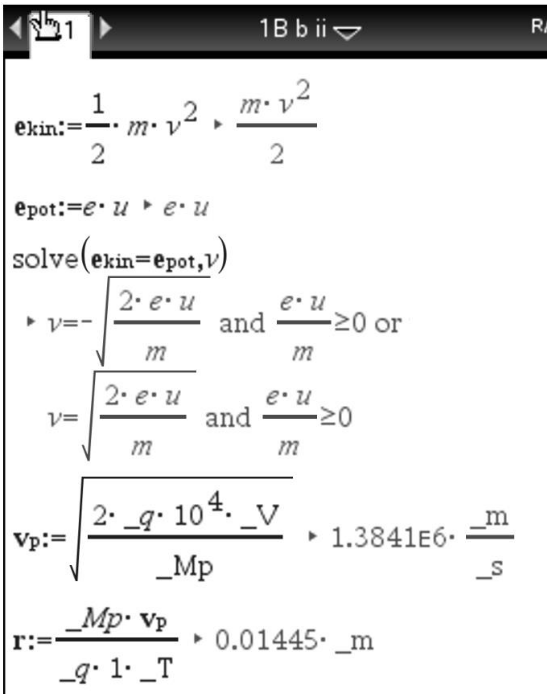
## 4. Marking Scheme and 5. Answer Sheet

<table>
<tr><th colspan="3">Solution to Question 1, Part A</th><th colspan="5">Fields</th></tr>
<tr><td colspan="3">A: Knowledge and Comprehension; B: Application; C: Analysis and Evaluation; W: Written Communication</td><td>A</td><td>B</td><td>C</td><td>W</td><td>Σ</td></tr>
<tr><td>a)</td><td></td><td>

<table>
<tr><th></th><th>A planet</th><th>B r</th><th>C t</th><th>D const</th></tr>
<tr><td>=</td><td></td><td></td><td></td><td>='t^2/'r^3</td></tr>
<tr><td>1</td><td>b</td><td>1.73</td><td>1.51</td><td>0.44037</td></tr>
<tr><td>2</td><td>c</td><td>2.37</td><td>2.42</td><td>0.43993</td></tr>
<tr><td>3</td><td>d</td><td>3.33</td><td>4.05</td><td>0.4442</td></tr>
<tr><td>4</td><td>e</td><td>4.38</td><td>6.1</td><td>0.44283</td></tr>
<tr><td>5</td><td>f</td><td>5.76</td><td>9.21</td><td>0.44387</td></tr>
<tr><td>6</td><td>g</td><td>7.01</td><td>12.35</td><td>0.44277</td></tr>
<tr><td>7</td><td>h</td><td>9.27</td><td>18.77</td><td>0.44227</td></tr>
</table>

Kepler's 3rd law gives (nearly) the same value of the ratio $\frac{T^2}{r^3}$ for all the planets. (As stated in the question, this ratio needs to be calculated and shown to be constant for only two planets.)</td><td>2</td><td></td><td></td><td>1</td><td>3</td></tr>
<tr><td>b)</td><td></td><td>
$$v_e = \frac{s}{t} = \frac{2\pi\, r_e}{T_e}$$
$$= \frac{2\pi\left(4.38\times 10^9\right)}{6.10\times 24\times 3600} = 5.22\times 10^4\ \text{m s}^{-1} = 52.2\ \text{km s}^{-1}$$
</td><td>2</td><td>1</td><td></td><td></td><td>3</td></tr>
<tr><td>c)</td><td></td><td>
According to Kepler's 3rd Law:
$$\frac{T_1^2}{r_1^3} = \frac{T_2^2}{r_2^3} \qquad \left(T = \frac{s}{v} = \frac{2\pi r}{v} \Rightarrow T^2 = \frac{4\pi^2 r^2}{v^2}\right)$$
$$\frac{4\pi^2 r_1^2}{r_1^3 v_1^2} = \frac{4\pi^2 r_2^2}{r_2^3 v_2^2} \Rightarrow r_1 v_1^2 = r_2 v_2^2 \Rightarrow \left(\frac{v_1}{v_2}\right)^2 = \frac{r_2}{r_1}$$
$$\Rightarrow \frac{v_1}{v_2} = \sqrt{\frac{r_2}{r_1}}$$
Alternative solution:<br>
Gravitational force = Centripetal force
$$|F_G| = |F_C| \Leftrightarrow G\,\frac{M\,m}{r^2} = \frac{m\,v^2}{r} \quad \Rightarrow v^2 = \frac{G\,M}{r}$$
$$\Rightarrow \frac{v_1^2}{v_2^2} = \frac{\frac{G\,M}{r_1}}{\frac{G\,M}{r_2}} = \frac{r_2}{r_1} \qquad \Rightarrow \frac{v_1}{v_2} = \sqrt{\frac{r_2}{r_1}}$$
</td><td></td><td>1</td><td>2</td><td></td><td>3</td></tr>
</table>

## 4. Marking Scheme and 5. Answer Sheet

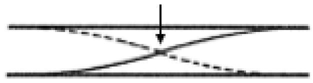
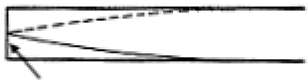
| | | **Solution to Question 1, Part A** | **Fields** | | | | |
|---|---|---|---|---|---|---|---|
| **d)** | | Using the equation from part **c)**, and comparing with planet "e", whose speed is known from part **b)**, gives:<br>$\frac{v_e}{v_x} = \sqrt{\frac{r_x}{r_e}} \Rightarrow r_x = r_e \left(\frac{v_e}{v_x}\right)^2$<br>$\Rightarrow r_x = 4.38 \times 10^9 \left(\frac{5.22 \times 10^4}{4.13 \times 10^4}\right)^2$<br>$\Rightarrow r_x = 7.00 \times 10^9 \text{ m} = 7.00 \times 10^6 \text{ km}$<br>It is planet "g".<br> | | 1<br>1 | | 0.5<br>0.5 | **3** |
| **e)** | **i.** | $E_{tot} = E_{kin} + E_{pot} = \frac{1}{2} m v^2 - G\frac{m\,M}{r}$<br>Since $F_G = F_C \Rightarrow G\frac{m\,M}{r^2} = \frac{m\,v^2}{r} \Rightarrow v^2 = \frac{G\,M}{r}$<br>$\Rightarrow E_{tot} = E_{kin} + E_{pot} = \frac{G\,m\,M}{2\,r} - G\frac{m\,M}{r} = -G\frac{m\,M}{2\,r}$ | | 2 | 1 | | **3** |
| | **ii.** | $E_{tot} = -G\frac{m\,M}{2r}$<br>$E_{tot} = -6.67 \times 10^{-11} \times \frac{0.77 \times 5.97 \times 10^{24} \times 1.77 \times 10^{29}}{2 \times 4.38 \times 10^9}$<br>$E_{tot} = -6.20 \times 10^{33}$ J | | 1 | | | **1** |
| | | | 4 | 7 | 3 | 2 | **16** |

| | | **Solution to Question 1, Part B** | **Fields** | | | | |
|---|---|---|---|---|---|---|---|
| | | A: Knowledge and Comprehension; B: Application; C: Analysis and Evaluation; W: Written Communication | **A** | **B** | **C** | **W** | **Σ** |
| **a)** | **i.** | The centripetal force required is supplied by the magnetic field.<br>$F_m = F_C$<br>$\Rightarrow Be\,v = \frac{m_P\,v^2}{R}$<br>$\Rightarrow R = \frac{m_P\,v}{e\,B}$<br><br> | | 1.5 | 1.5 | | **3** |
| | **ii.** | The distance travelled during the time $\Delta t$ is half the circumference of a circle having radius $R$:<br>$v = \frac{\Delta s}{\Delta t} = \frac{\pi R}{\Delta t} \Rightarrow \Delta t = \frac{\pi R}{v}$<br>Inserting $R$ from **i.** gives $\Delta t = \frac{\pi\,m_P}{e\,B}$. Hence $\Delta t$ is independent of the speed $v$.<br><br> | 2 | | | | **2** |
| **b)** | **i.** | The potential energy of a charge $e$ in an electric field of potential difference $U$ is $E_{pot} = e\,U$.<br>During each gap crossing the potential energy is converted into kinetic energy. Hence, the increase in kinetic energy of the proton for each gap crossing is $\Delta E_{kin} = e \times 1.00 \times 10^4\ \text{V} = 1.00 \times 10^4\ \text{eV}$. | 1.5 | | | 0.5 | **2** |
| | **ii.** | For the first gap crossing the initial value of the kinetic energy of the proton is 0. $\Rightarrow \Delta E_{kin} = E_{kin} - 0 = E_{kin}$<br>$E_{kin} = E_{pot} \Rightarrow \frac{1}{2} m_P\,v^2 = e\,U$<br>$\Rightarrow v = \sqrt{\frac{2\,e\,U}{m_P}}$<br>Inserting this formula for $v$ into the equation from a) i. gives<br>$R_1 = \frac{m_P\,v_1}{e\,B} = \sqrt{\frac{m^2_P}{e^2\,B^2} \times \frac{2\,e\,U}{m_P}}$<br>$= \sqrt{\frac{2\,m_P\,U}{e\,B^2}}$<br>$= \sqrt{\frac{2 \times 1.67 \times 10^{-27} \times 1 \times 10^4}{1.60 \times 10^{-19} \times 1}}$<br>$= 0.0144\text{m} = 1.44\ \text{cm}$<br><br> | 2 | 1 | | | **3** |

## 4. Marking Scheme and 5. Answer Sheet

<table>
<tr><th colspan="4">Solution to Question 1, Part B</th><th colspan="5">Fields</th></tr>
<tr>
<td>c)</td>
<td>i.</td>
<td>Using the equation in a) i:<br>
$$v_{\max} = \frac{e\,B\,R_{\max}}{m_{P}} \text{ and}$$
$$E_{\text{kin max}} = \frac{1}{2} m v_{\max}^{2} \text{ we get}$$
$$E_{\text{kin max}} = \frac{1}{2} m_{P} \left( \frac{eBR_{\max}}{m_{P}} \right)^{2}$$
$$E_{\text{kin max}} = \frac{(1.6\times10^{-19}\times1\times0.289)^{2}}{2\times1.67\times10^{-27}}$$
$$= 6.40\times10^{-13}\text{ J}$$
$$= 4.00\times10^{6}\text{ eV} = 4.00\text{ MeV}$$</td>
<td>1.1 | 1B c i<br>
$r_{max}$:=0.289·_m ▸ 0.289·_m<br>
vm:=right(solve($r_{max}=\frac{\_Mp\cdot v_{max}}{\_q\cdot 1\cdot \_T}$,$v_{max}$)) ▸ 2.7683E7·$\frac{\_m}{\_s}$<br>
em:=$\frac{1}{2}$·_Mp·vm$^{2}$ ▸ 6.409E−13·_J<br>
em▸_eV ▸ 4.0002E6·_eV</td>
<td>1</td><td>2</td><td></td><td></td><td>3</td>
</tr>
<tr>
<td></td>
<td>ii.</td>
<td>Dividing the maximum kinetic energy from c) i. by the energy received during each gap crossing (see b) i., we get the number of gap crossings n.<br>
$$n = \frac{4.00\times10^{6}\text{ eV}}{1.00\times10^{4}\text{ eV}}$$
$$= 400 \text{ gap crossings,}$$
i.e. 200 revolutions</td>
<td>1.1 | 1B c i<br>
em▸_eV ▸ 4.0002E6·_eV<br>
e1:=1·10$^{4}$·_eV ▸ 1.6022E−15·_J<br>
n:=$\frac{em}{e1}$ ▸ 400.02</td>
<td></td><td></td><td>1</td><td></td><td>1</td>
</tr>
<tr><td colspan="4"></td><td>6.5</td><td>4.5</td><td>2.5</td><td>0.5</td><td>14</td></tr>
</table>

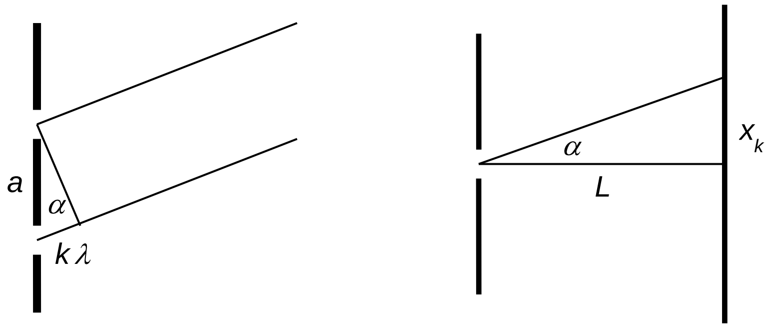
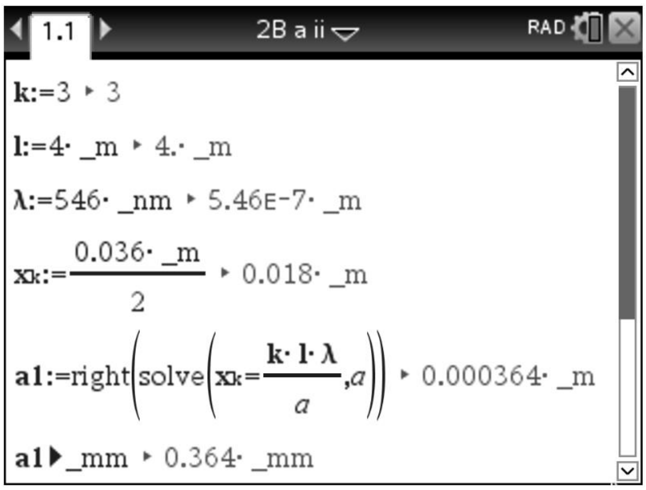
## 4. Marking Scheme and 5. Answer Sheet

| | | | | | A | B | C | W | Σ |
|---|---|---|---|---|---|---|---|---|---|
| **Solution to Question 2, Part A** | | | | | | | | | |
| A: Knowledge and Comprehension; B: Application; C: Analysis and Evaluation; W: Written Communication | | | | | **A** | **B** | **C** | **W** | **Σ** |
| **a)** | **i.** | | **open at both ends** | **closed at one end** | | | | | **4** |
| | | **fundamental** |  |  | 1<br>1 | | | | |
| | | **1st Overtone** |  |  | 1<br>1 | | | | |
| | | (The arrows show the positions of the nodes.) | | | | | | | |
| | **ii.** | The wavelength of a sound with frequency 20 Hz is<br>$c = \lambda f \Rightarrow \lambda = \frac{c}{f} = \frac{346}{20} = 17.3\,\text{m}$ | | | | 2 | | | **3** |
| | | The length of an open pipe is half the fundamental wavelength:<br>$L_{\text{open}}$ = 8.65 m. | | | 0.5 | | | | |
| | | The length of a closed pipe is a one quarter of the fundamental wavelength:<br>$L_{\text{closed}}$ = 4.325 m. | | | 0.5 | | | | |
| | **iii.** | From the sketches in a) i., for the same $L$, one can see the relation between the wavelengths for the first overtones for both types of pipes<br>$\frac{\lambda_{\text{open},1}}{\lambda_{\text{closed},1}} = \frac{L}{\frac{4}{3}L} = \frac{3}{4}$ and since $f \propto \frac{1}{\lambda} \Rightarrow \frac{f_{\text{open},1}}{f_{\text{closed},1}} = \frac{4}{3}$ | | | | | 2 | | **2** |
| | | **Alternative solution:**<br>You could also get this ratio using the formulae:<br>$\lambda_{\text{open},\,n} = \frac{2L}{n+1}$ and $\lambda_{\text{closed},\,n} = \frac{4L}{2n+1}$, where $n = 0,1,2,3,\ldots\ldots$<br>When $n = 1$: $\frac{\lambda_{\text{open},\,1}}{\lambda_{\text{closed},\,1}} = \frac{2L}{2} \div \frac{4L}{3} = \frac{3}{4} \Rightarrow \frac{f_{\text{open},\,1}}{f_{\text{closed},\,1}} = \frac{4}{3}$ since $f \propto \frac{1}{\lambda}$ | | | | | | | |

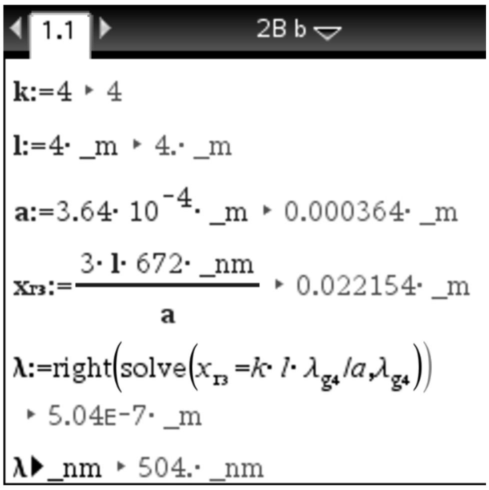
**4. Marking Scheme** and **5. Answer Sheet**

| Solution to Question 2, Part A | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **b)** | **i.** | The frequency of the note has to be divided by 2 four times. $\frac{440\,\text{Hz}}{2^4} = 27.5\,\text{Hz} > 20\,\text{Hz}$. Hence the human ear can hear this note. | | 2 | | | | **2** |
| | **ii.** | **1.** | $\frac{14\ 080}{440} = 32 = 2^5$, where 5 is the number of octaves above 440 Hz. | 1 | | | | **1** |
| | | **2.** | The wavelength of the sound with $f = 14\ 080$ Hz is: $\lambda = \frac{c}{f} = \frac{346\,\text{m s}^{-1}}{14\ 080\,\text{s}^{-1}} = 0.02457\,\text{m} = 24.57\,\text{mm}$. $\frac{\lambda}{L} = \frac{24.57}{6.14} = 4$. Since $\lambda = 4L$, it is a closed pipe. | | 2 | 1 | | **3** |
| | | | | 8 | 4 | 3 | 0 | **15** |

## 4. Marking Scheme and 5. Answer Sheet

| | | Solution to Question 2, Part B | | | | | |
|---|---|---|---|---|---|---|---|
| | | A: Knowledge and Comprehension; B: Application; C: Analysis and Evaluation; W: Written Communication | **A** | **B** | **C** | **W** | **Σ** |
| **a)** | **i.** |  | 1 | | | | **4** |
| | | For constructive interference to occur at a point on a screen, the path difference between the waves meeting at that point must be equal to a whole number multiple of the wavelength of the light. | | | | 0.5 | |
| | | $\frac{k\,\lambda}{a} = \sin\alpha \approx \tan\alpha = \frac{x_k}{L} \underset{\text{approximately}}{\Rightarrow} \frac{k\,\lambda}{a} = \frac{x_k}{L} \Rightarrow x_k = k\,\frac{L\,\lambda}{a}$ | | 0.5 | | | |
| | | The following approximations are used: | | | | | |
| | | Since *L>>a*, we can approximate rays from adjacent slits to the screen as being parallel to each other and at an angle *α* to the central axis. | 0.5 | | | 0.5 | |
| | | Since α is very small ($a \gg \lambda$), $\sin\alpha \approx \tan\alpha$ | 0.5 | | | 0.5 | |
| | **ii.** | $x_k = k\,\frac{L\,\lambda}{a}$<br>$\Rightarrow a = \frac{k\,L\,\lambda}{x_k}$<br>$= \frac{3 \times 4 \times 546 \times 10^{-9}}{0.036/2}$<br>$= 3.64 \times 10^{-4}\,\text{m}$<br>$= 0.364\,\text{mm}$ | 1 | 1 | | | **2** |
| | |  | | | | | |

## 4. Marking Scheme and 5. Answer Sheet

| | | Solution to Question 2, Part B | | | | | |
|---|---|---|---|---|---|---|---|
| **b)** | | $x_k = k\dfrac{L\,\lambda}{a} \Rightarrow x_{3r} = \dfrac{3\times 4.00\times 672\times 10^{-9}}{3.64\times 10^{-4}} = 22.15\,\text{mm}$<br><br>Because the green maximum must also be at $x_{3r}, \Rightarrow x_{\text{kgreen}} = 22.15$ mm<br><br>As $\lambda_{\text{green}} < \lambda_{\text{red}}$ it is sufficient to start with the 4th order green maximum:<br><br>$x_k = k\dfrac{L\,\lambda}{a} \Rightarrow \lambda = \dfrac{x_k a}{kL} \Rightarrow \lambda = \dfrac{22.15\times 10^{-3}\times 3.64\times 10^{-4}}{4\times 4.00} = 504\times 10^{-7}\,\text{mm}$.<br><br>This wavelength $504\times 10^{-7}\,\text{mm}$ is in the range given for green light.<br>Hence the 3rd red maximum overlaps the 4th green maximum.<br>Using $k \geq 5$ gives wavelengths lower than the range given for green light. | 0.5<br>0.5 | 1.5 | 1 | 0.5 | **4** |
| | |  | | | | | |
| **c)** | **i.** | $d = \dfrac{1}{\text{number of lines per metre}}$ = the grating constant<br>$\theta_k$ is the angle between the light rays forming the central maximum and the light rays forming the kth order maximum. | | | | 0.5<br>0.5 | **1** |
| | **ii.** | $\tan\,\theta_1 = \dfrac{x_1}{L} \Rightarrow \theta_1 = \tan^{-1}\dfrac{x_1}{L} = \tan^{-1}\dfrac{0.871}{4.00}$<br>$d = \dfrac{1}{4000\times 10^{2}}\ \text{m}^{-1}$<br>$\lambda = \dfrac{d\sin\theta}{k} = \dfrac{\dfrac{1}{4000\times 10^{2}}\times\sin\left(\tan^{-1}\dfrac{0.871}{4.00}\right)}{1} = 5.32\times 10^{-7}\text{m}$ | | 2<br>1 | 1 | | **4** |
| | | | 4 | 6 | 2 | 3 | **15** |

## 4. Marking Scheme and 5. Answer Sheet

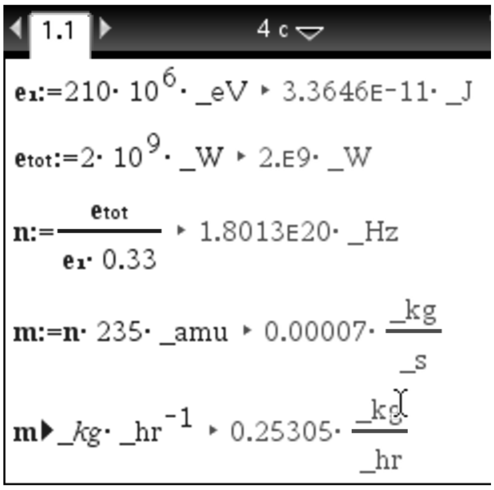
| Solution to Question 3 | | | | A | B | C | W | Σ |
|---|---|---|---|---|---|---|---|---|
| A: Knowledge and Comprehension; B: Application; C: Analysis and Evaluation; W: Written Communication | | | | A | B | C | W | Σ |
| **a)** | **i.** | | *hf*: the energy of a photon incident on the photoelectric cell<br>$W_0$: the work function, i.e. the minimum energy needed to release an electron from the surface of the photocathode<br>$E_{kin}$: the maximum kinetic energy of the released electron | 1.5 | | | 1.5 | **3** |
| | **ii.** | **1.** | $E_{photon} = hf = \frac{hc}{\lambda}$<br>$= \frac{6.63\times10^{-34}\times3.00\times10^{8}}{486\times10^{-9}}$<br>$= 4.09\times10^{-19}\,\text{J}$<br><br>[1.1 · 3 a ii · RAD]<br>wo:=2.08· _eV ▸ 3.3325E-19· _J<br>λ:=486· _nm ▸ 4.86E-7· _m<br>a:=100· _mm² ▸ 0.0001· _m²<br>f:=right(solve(_c=λ· f,f)) ▸ 6.1686E14· _Hz<br>$e_{ph}$:=_h· f ▸ 4.0873E-19· _J<br>... | 3 | | | | **3** |
| | | **2.** | Part of the energy of the photon is used to set the electron free. The remainder of the photon's energy is the kinetic energy of the free electron.<br>$E_{kinmax} = E_{photon} - W = hf - W$<br>$E_{kinmax} = 4.09\times10^{-19} - 2.08\left(1.60\times10^{-19}\right)$<br>$= 7.62\times10^{-20}\ \text{J}\quad (= 0.476\ \text{eV})$<br><br>[1.1 · 3 a ii]<br>...<br>ekin:=eph−wo ▸ 7.5481E-20· _J<br>... | 1 | 1 | | | **2** |
| | | **3.** | $n$ is the number of photons incident on the photocathode per second.<br>$P = n\,E_{photon} \Rightarrow n = \frac{P}{E_{photon}}$<br>$= \frac{1\times10^{-1}\times100\times10^{-6}}{4.09\times10^{-19}}$<br>$= 2.44\times10^{13}\,\text{s}^{-1}$<br><br>...<br>p:=0.1· $\frac{\_W}{\_m^2}$· a ▸ 0.00001· _W<br>n:=$\frac{p}{e_{ph}}$ ▸ 2.4466E13· _Hz<br>... | 1 | 1 | 2 | | **4** |
| | | **4.** | Only 4% of the incident photons release an electron.<br>$n'$ is the number of photons which actually cause photoemission per second.<br>$n' = \frac{4}{100}\times2.44\times10^{13}\,\text{s}^{-1} = 9.76\times10^{11}\,\text{s}^{-1}$.<br>$I = \frac{Q}{t} = e\,n' = \frac{1.60\times10^{-19}\times9.76\times10^{11}}{1}$<br>$= 1.56\times10^{-7}\,\text{A}$<br><br>...<br>i:=0.04· n· _q ▸ 1.5679E-7· _A | | 2 | 2 | | **4** |

**4. Marking Scheme** and **5. Answer Sheet**

| **Solution to Question 3** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **b)** | | In a) ii. 2. the energy of a photon with wavelength 486 nm is given as<br>$E_{\text{photon}} = 4.09\times10^{-19}\,\text{J} = \frac{4.09\times10^{-19}}{1.60\times10^{-19}}\,\text{eV} \approx 2.56\,\text{eV}$ .<br>$\Delta E = -3.40 - E_n = -2.56$<br>$\Rightarrow E_n = -3.40 + 2.56 = -0.84\,\text{eV} \Rightarrow n = 4$<br>Hence the transition is from level 4 to level 2. | | 2<br>1.5 | | 0.5 | **4** |
| | | | 6.5 | 7.5 | 4 | 2 | **20** |

**4. Marking Scheme** and **5. Answer Sheet**

| | | **Solution to Question 4** | | | | | |
|---|---|---|---|---|---|---|---|
| | | A: Knowledge and Comprehension; B: Application; C: Analysis and Evaluation; W: Written Communication | **A** | **B** | **C** | **W** | **Σ** |
| **a)** | **i.** | The atoms of each isotope of an element have the same number of protons (i.e. the same atomic number) but have a different number of neutrons (i.e. a different mass number). | 1 | | | | **1** |
| | **ii.** | $^{99}_{43}\text{Tc}$ has 43 protons and 99 - 43 = 56 neutrons. | 0.5 | | | 0.5 | **1** |
| | **iii.** | $^{99}_{43}\text{Tc} \to {}^{99}_{44}\text{Ru} + {}^{0}_{-1}\text{e} + \left({}^{0}_{0}\bar{\nu}\right) = {}^{99}_{44}\text{Ru} + \beta^- + \left({}^{0}_{0}\bar{\nu}\right)$. It is $\beta^-$ decay.<br>(The anti-neutrino need not be given by students.) | 1 | 1 | | | **2** |
| | **iv.** | The half- life of a radioactive isotope is the time taken for the number of radioactive nuclei $N$ to fall to half of the original value $N_0$. | 0.5 | | | 0.5 | **1** |
| | **v.** | The graph starts at time $t=0$ with an activity of 4000 Bq and falls to 1000 Bq after about 12 h. So the half-life is 6 h (approximately).<br>(Other points of the graph may be chosen.) | | 0.5 | | 0.5 | **1** |
| | **vi.** | $\frac{1}{2}N_0 = N_0\,e^{-\lambda T_{1/2}} \Rightarrow \frac{1}{2} = e^{-\lambda T_{1/2}} \Rightarrow \ln\frac{1}{2} = -\lambda T_{1/2} \Rightarrow -\ln 2 = -\lambda T_{1/2} \Rightarrow T_{1/2} = \frac{\ln 2}{\lambda}$ | | 2 | | | **2** |
| **b)** | **i.** | A chain reaction occurs when at least one neutron from each fission reaction causes further fission to produce more fission neutrons, so that the fission reaction is self-sustaining. | 1 | | | 0.5 | **4** |
| | | The neutrons released by the fission of $^{235}\text{U}$ are fast neutrons and must be slowed down in order to cause further fission in $^{235}\text{U}$ which is only fissionable by slow neutrons. Moderators e.g. heavy water or graphite, slow down the fast neutrons to speeds which allow them to cause fission of $^{235}\text{U}$ atoms. | | 1.5 | 0.5 | 0.5 | |
| | **ii.** | Mass of the reactants - Mass of the products $=\Delta m$ | | | | | **4** |
| | | $[m\left({}^{235}_{92}\text{U}\right) - 92m_e + m_n] - [m\left({}^{141}_{56}\text{Ba}\right) - 56m_e + m\left({}^{92}_{36}\text{Kr}\right) - 36m_e + 3m_n] = \Delta m$ | | 2 | | | |
| | | (If the student explains that the total number of electrons does not change, it is not necessary to mention them in the above equation.) | | | | | |
| | | $\Delta m = m\left({}^{235}_{92}\text{U}\right) - m\left({}^{141}_{56}\text{Ba}\right) - m\left({}^{92}_{36}\text{Kr}\right) - 2m_n$ | 1 | | | | |
| | | $\Delta m = 235.043930 - 140.914411 - 91.926156 - 2(1.008665)$<br>$\Delta m = 0.186033\ \text{u}$ | | | | | |
| | | $\Delta m = 0.186033 \times 931.5\ \frac{\text{MeV}}{\text{c}^2} = 173.3\frac{\text{MeV}}{\text{c}^2}$ | 1 | | | | |
| | | $\Delta E = \Delta mc^2 = 173.3\text{MeV} = E_{\text{fission}}$ | | | | | |

| **Solution to Question 4** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **c)** | | $2\text{ GW} = 2\,\frac{\text{GJ}}{\text{s}}$<br>$= 2 \times 3600\text{ GJ per hour}$ .<br>$= 7.20 \times 10^{12}\text{ J per hour}$<br><br>The number of fission reactions needed per hour, *n*, (taking into account the efficiency), is:<br><br>$n = \frac{7.2 \times 10^{12}}{E_{\text{fission}} \times 0.33}$<br>$= \frac{7.2 \times 10^{12}}{210 \times 10^{6} \times 1.6 \times 10^{-19} \times 0.33}$ .<br>$= 6.49 \times 10^{23}$ fissions per hour<br><br>The mass needed per fission reaction is: $m_1 = 235\text{ u} = 235 \times 1.66 \times 10^{-27}\text{kg}$<br>$= 3.90 \times 10^{-25}\text{kg}$ .<br><br>The total mass needed per1 hour:<br><br>$m = m_1 \times n = 3.90 \times 10^{-25} \times 6.49 \times 10^{23}$<br>$= 0.253\text{ kg per hour.}$ |  | 1 | | 1<br><br>1<br><br>1 | | **4** |
| | | | | 7 | 7 | 3.5 | 2.5 | **20** |

## 6. Excel Table to help checking marks

# EE: BAC Physics ....

| Question 1 | Knowledge and Comprehension | Application | Analysis and Evaluation | Written Communication | Σ |
|---|---|---|---|---|---|
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| Sum A: | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| Sum B: | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| **Sum:** | **0,0** | **0,0** | **0,0** | **0,0** | **0,0** |
| **%:** | **0,0** | **0,0** | **0,0** | **0,0** | |
| Target: | 11,0 | 11,0 | 5,0 | 3,0 | 30,0 |

| Question 2 | Knowledge and Comprehension | Application | Analysis and Evaluation | Written Communication | Σ |
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| Sum A: | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| Sum B: | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| **Sum:** | **0,0** | **0,0** | **0,0** | **0,0** | **0,0** |
| **%:** | **0,0** | **0,0** | **0,0** | **0,0** | |
| Target: | 11,0 | 11,0 | 5,0 | 3,0 | 30,0 |

| Question 3 | Knowledge and Comprehension | Application | Analysis and Evaluation | Written Communication | Σ |
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| **%:** | **0,0** | **0,0** | **0,0** | **0,0** | |
| Target: | 7,0 | 7,0 | 4,0 | 2,0 | 20,0 |

| Question 4 | Knowledge and Comprehension | Application | Analysis and Evaluation | Written Communication | Σ |
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| **Sum:** | **0,0** | **0,0** | **0,0** | **0,0** | **0,0** |
| **%:** | **0,0** | **0,0** | **0,0** | **0,0** | |
| Target: | 7,0 | 7,0 | 4,0 | 2,0 | 20,0 |

The fields marked in yellow can be filled in, all others are protected.

| | | |
|---|---|---|
| The Sums are marked in different colors: | green: | ok |
| | orange: | within tolerance |
| | red: | not allowed |