Question	Evidence	1-4 marks	5-6 marks	7-8 marks
1(a)	The dark lines correspond to light that has the correct energy to excite transitions between the quantised energy levels of electrons of the atoms (or molecules) in the gas. The light is absorbed by the gas and re-emitted (in all directions), and so there is a strong dip in the intensity of the spectrum at these energies, causing dark lines.	Shows some understanding of the underlying physics. AND / OR (partially) correct mathematical solution to given problem.	A reasonable understanding of the underlying physics. AND (partially) correct mathematical solution to given problem.	Thorough understanding of the underlying physics. AND Correct mathematical solution to the given problem.
(b)	Diffraction illustrates the wave aspect of light. Diffraction is the spreading out of a wavefront when passing through a gap or obstacle. The wavefront acts a series of secondary sources. A stream of particles passing through a gap would not spread out in this manner. Light striking a metal surface can lead to emission of an electron. That electron's maximum energy is directly related to the frequency of the incident light and not the intensity.			
(c)	Approximately 90% of photons emitted by a hot filament light bulb are in the infrared, so 10 W of visible photons are being emitted. A typical wavelength for visible photons is 500 nm. Therefore, energy of photon, $E=\frac{\text{hc}}{\lambda}=\frac{6.63\times10^{-34}\ \text{J s}\times3.00\times10^{8}\ \text{m s}^{-1}}{5.00\times10^{-7}\ \text{m}}=3.98\times10^{-19}\ \text{J}$ The number of photons emitted $=\frac{10\ \text{J s}^{-1}}{3.98\times10^{-19}\ \text{J}}=0.25\times10^{20}$ photons per second, ie approximately 10^{19} photons per second			
(d)	To achieve fusion, the two nuclei would have to just touch (ie approach within at least one nuclear radius), ie 10^{-15} m. For two deuterium nuclei that were originally well apart, the kinetic energy needed to make them approach within one nuclear radius will be very high due to electrostatic repulsion. At room temperature very few nuclei would have the required kinetic energy, making fusion unlikely.			

Question	Type 1 (explanatory) or Type 2 (problem)	B Evidence	A Evidence
			kinetic energy of alpha particle = 0.98 *E*
2	1	Candidates must include the following: - Explanation of wave–particle duality - Experimental example of wave behaviour - Experimental example of particle behaviour **Explanation of wave–particle duality:** Candidates need to demonstrate an understanding that the behaviour of light in some experiments can only be understood in terms of waves, and in other experiments it can only be explained by particles. **Experimental example of wave behaviour:** Candidates will use choose at least one wave behaviour and explain it but will tend to introduce irrelevancies in relation to the description. **Experimental example of particle behaviour:** Candidates will state at least one particle behaviour from the photoelectric effect. Candidates will tend to introduce irrelevancies in relation to the description.	Candidates must include the following: - Explanation of wave–particle duality - Experimental example of wave behaviour - Experimental example of particle behaviour **Explanation of wave–particle duality:** Candidates need to demonstrate an understanding that the behaviour of light in some experiments can only be understood in terms of waves, and in other experiments it can only be explained by particles. This has lead to the idea that light has to be thought of as both a wave and a particle, implying that these apparently different concepts are in fact closely related. This dual nature is known as wave–particle duality. **Experimental example of wave behaviour:** Candidates could use diffraction, interference, refraction* or polarisation* as examples of this. They need to describe the phenomena chosen and briefly explain it in terms of waves. (* not on NCEA level 3 syllabus) **Experimental example of particle behaviour:** Candidates have studied the photoelectric effect so will probably use this as an example. They need to describe the photoelectric effect and briefly explain it in terms of particles.

Q	Evidence	1-4 marks	5-6 marks	7-8 marks
THREE (a)	hf = work function + E_k $E_k = 1.31 \times 1.60 \times 10^{-19}$ J $= 2.096 \times 10^{-19}$ J $hf = \frac{6.63\times10^{-34}\times3\times10^{8}}{375\times10^{-9}} = 5.304\times10^{-19}$ J work function = 3.208×10^{-19} J	Thorough understanding of these applications of physics. OR Partially correct mathematical solution to the given problems. AND / OR Partial understanding of these applications of physics.	(Partially) correct mathematical solution to the given problems. AND / OR Reasonably thorough understanding of these applications of physics.	Correct mathematical solution to the given problems. AND Thorough understanding of these applications of physics.
(b)	Diameter of the beam = $3.80 \times 10^{8} \times 1.65 \times 10^{-3}$ m Area illuminated = $\pi r^2 = 3.09 \times 10^{11}$ m^2 Energy of a single photon = $hf = \frac{hc}{\lambda} = 3.42\times10^{-19}$ J The number of photons per second = $\frac{0.45\times10^{-3}}{3.42\times10^{-19}} = 1.31\times10^{15}$ The number of photons s^{-1} m^{-2} = $\frac{1.31\times10^{15}}{3.09\times10^{11}} = 4260$			
(c)	Conservation of momentum states that: $\frac{h}{\lambda_1} = -\frac{h}{\lambda_2} + m_e v$ Conservation of energy states that: $hf_1 = hf_2 + \frac{1}{2}m_e v^2$ and since $c = f\lambda$ $\frac{h}{\lambda_1} = \frac{h}{\lambda_2} + \frac{1}{2c}m_e v^2$ Finally $\frac{2hc}{\lambda_1} = \frac{1}{2}m_e v^2 + m_e vc$ For 4.00 keV electrons the kinetic energy = 6.4×10^{-16} J Using $E_k = \frac{1}{2}mv^2$ gives $v = 3.7484 \times 10^{7}$ m s^{-1} $\frac{2hc}{\lambda_1} = 6.4 \times 10^{-16} + 1.0244 \times 10^{-14} = 1.088 \times 10^{-14}$ The final wavelength = 3.65×10^{-11} m			
(d)	Each electron comes with its own proton. The 1 gram of hydrogen is almost entirely single protons, so there are about as many electrons as there are protons. In all the other light elements, half the mass is composed of neutrons so half the mass is protons, meaning half the number of electrons in the 1 gram mass. The number of electrons is only approximately half because both hydrogen and the light elements have isotopes with differing numbers of neutrons which usually serve to reduce the number of protons (and hence the number of electrons) in any given mass. (But not in the case of He3).			

Q	Evidence	1-4 marks	5-6 marks	7-8 marks
4(a)(i)	The photoelectric effect is the observed release of electrons when sufficiently energetic photons impact on the metal surface. Below the energetic threshold, no electrons are released. At the energetic threshold, electrons of zero kinetic energy are produced. The incident photon delivers a fixed amount of energy ($E = hf$). The incident energy of the photon equals the kinetic energy of the liberated electron plus the energy required to liberate the electron (work function).	Thorough understanding of these applications of physics. OR Partially correct mathematical solution to the given problems. AND / OR Partial understanding of these applications of physics.	(Partially) correct mathematical solution to the given problems. AND / OR Reasonably thorough understanding of these applications of physics.	Correct mathematical solution to the given problems. AND Thorough understanding of these applications of physics.
(ii)	The classical explanation should have resulted in a time delay of the release of the electrons – no time delay was measured. No lower limit would exist for the incident frequency to eventually release electrons. Idea of the photon is required to explain the phenomenon.			
(b)	Similarities: • Both experience a centripetal force, and both forces are inversely proportional to the square of the orbital radius. • Both orbit about the centre of mass of the system (not about the centre of mass of the more massive object in the system). Differences: • The centripetal force is supplied by electrostatic attraction in the hydrogen atom and by gravitational force in the Earth / Moon system. • The electron orbits are obviously quantised (restricted to specific possible values), while the possible orbital radius of the Moon is effectively continuous. (The gap between the quantum levels of the Moon's orbit is unmeasurably small.)			
(c)(i)	At maximum, both waves arrive in phase. As the frequency increased, the wavelength decreases (constant velocity) and therefore, as the path difference is constant, at some frequency the waves will be completely out of phase (minima).			
(ii)	The lowest frequency to generate a maximum = 200 Hz. The longest wavelength is 1.2 m. The path difference is unchanged throughout. This means that at 200 Hz the path difference was 1 wavelength which is 1.2 m. Speed of sound $= f\lambda$ $= 240$ m s^{-1}			

Q	Evidence	1-4 marks	5-6 marks	7-8 marks
5 (a)	*Photoelectric effect.* Electrons in the conduction band of metals do not require large amounts of energy to escape from the host atom. Light consists of photons – energy packets whose energy is directly proportional to the frequency of the photons. If the energy needed to release an electron is less than the energy carried by a photon, then when the photon interacts with the electron, the photon can be absorbed by the electron which gains all the photon's energy, converting some of that energy into potential energy in the act of leaving the atom and the rest (if there is any) into KE. Single electrons can be released by single photons, showing that light (and therefore energy) is quantised – exists in distinct packets. *Hydrogen spectrum.* The electron associated with a single proton (forming a hydrogen atom) has a restricted set of possible energy values. We say the energy held by the electron is quantised because when the electron changes from large PE to less PE, the energy change is released as an electromagnetic photon and these photons always have precise values, forming the hydrogen emission spectrum. The quantisation of energy would be the link between these phenomena.	Some understanding of these applications of physics.	Reasonably thorough understanding of these applications of physics.	Thorough understanding of these applications of physics.
(b)	The fusion of deuterium to helium will release about 6 MeV per nucleon. The fission of U to Fe (the largest possible fission energy gap) will release about 1 MeV per nucleon. Fusion releases more energy per nucleon than fission, but fission processes involve more nucleons, and so can release greater total amounts of energy per fission reaction than a fusion reaction will release.			
(c)	The atoms of the intervening hydrogen interact with photons that have frequencies that deliver exactly the correct energy. The electrons of hydrogen atoms can accept only specific amounts of energy in the process of becoming excited. Only photons of specific frequency will carry these precise energy amounts, and it is these photons that will be absorbed (and "used" to excite electrons) in the passage of the radiation through the hydrogen. The emerging light will therefore be missing just those frequencies that can excite hydrogen electrons. The missing frequencies will show up as dark lines in the spectrum of the light. The excited electrons will soon reradiate the missing photons, but the re-radiation will be in a random direction and so not many of the reradiated photons will travel in the direction of the original beam.			

Q	Evidence	1-4 marks	5-6 marks	7-8 marks
6 (a)(i)	The energy of any incident photon = $\mathrm{h}f = \frac{\mathrm{hc}}{\lambda}$ The minimum energy required to liberate an electron from the metal surface is ϕ (the work function). Any difference between the work function energy and the incident photon energy will manifest as the maximum kinetic energy of the liberated photons. $\frac{1}{2}mv^2 = \frac{\mathrm{hc}}{\lambda} - \phi$ The KE of the electron can also be expressed as the equivalent electric potential energy $\frac{1}{2} mv_{\mathrm{max}}^2 = V_{\mathrm{max}}\mathrm{e}$ (where V = the potential (voltage) required to accelerate an electron from rest to velocity v) So $V_{\mathrm{max}}\mathrm{e} = \frac{\mathrm{hc}}{\lambda} - \phi$	Thorough understanding of these applications of physics. OR Partially correct mathematical solution to the given problems AND / OR Partial understanding of these applications of physics.	(Partially) correct mathematical solution to the given problems. AND / OR Reasonably thorough understanding of these applications of physics.	Correct mathematical solution to the given problems. AND Thorough understanding of these applications of physics.
(ii)	The classical wave explanation would expect that increasing intensity of incident radiation would lead to an increase in the KE_{max} of the liberated electrons. Also light of any frequency would be capable of liberating electrons as long as sufficient time was given for the incoming energy to rise to whatever level the electrons required for liberation. Experiment showed that intensity is proportional only to the numbers of electrons released and not to their $\mathrm{KE}_{\mathrm{max}}$ which is dependent only on the frequency of the incident light. It is also found that low intensity, high frequency light will cause electron release immediately while high intensity, low frequency light will never achieve electron liberation, no matter how much energy is delivered over any period of time. The classical explanation failed and was replaced by a model of the radiation energy being delivered in small packets, photons, whose energy depended only on their frequency.			
(b)(i)	Mass lost (Δm) = $\frac{\Delta E}{\mathrm{c}^2} = \frac{200\times10^6\times1.6\times10^{-19}}{9\times10^{16}}$ = 3.55 × 10^{-28} kg The mass lost per equal mass is 1.775 × 10^{-28} kg. Their original mass was 1.965 × 10^{-25} kg so their rest mass is 1.963225 × 10^{-25} kg.			
(ii)	Because $(1-\frac{v^2}{\mathrm{c}^2})$ will always be less than 1 (for any moving mass) the actual mass of a moving object will always be greater than the rest mass (m_o). The equation expresses the gain in mass any moving object undergoes.			

Q	Evidence	1-4 marks	5-6 marks	7-8 marks
(iii)	Initial mass (M_{I}) = 3.93 × 10^{-25} kg (2.2106 × 10^5 MeV) Final mass of one part (M_{O}) = $\frac{M_{\mathrm{I}} - 200\text{ MeV}}{2}$ (1.1043 × 10^5 MeV; 1.9632 × 10^{-25} kg) Mass of M_{O} while moving at velocity V (call it M_{M}) $M_{\mathrm{M}} = \frac{M_{\mathrm{O}}}{\sqrt{1-\frac{V^2}{\mathrm{c}^2}}}$ The KE of this M_{O} is given by $E = \Delta M\mathrm{c}^2 = (M_{\mathrm{M}} - M_{\mathrm{O}})\mathrm{c}^2$ (The gain in KE IS the gain in mass, the ($M_{\mathrm{M}} - M_{\mathrm{O}}$)) KE = $(M_{\mathrm{M}} - M_{\mathrm{O}})\mathrm{c}^2$ $100\ MeV = (\frac{M_{\mathrm{O}}}{\sqrt{1-\frac{V^2}{\mathrm{c}^2}}} - M_{\mathrm{O}})\mathrm{c}^2$ $\sqrt{1-\frac{V^2}{\mathrm{c}^2}} = \frac{M_{\mathrm{O}}}{\frac{100\text{ MeV}}{\mathrm{c}^2} + M_{\mathrm{O}}} = 0.999094$ $1-\frac{V^2}{\mathrm{c}^2} = 0.999094^2 = 0.99819$ $\frac{V^2}{\mathrm{c}^2} = 1.8109\times10^{-3}$ $V = 0.1277\times10^8\ \mathrm{m\ s^{-1}}$			

Question	Evidence	1-4 marks	5-6 marks	7-8 marks
7 (a)	Kinetic energy $E_K = \frac{1}{2}mv^2$ $\Rightarrow E_K = \frac{p^2}{2m}$ $p = \sqrt{2mE}$ $\lambda = \frac{h}{p}$ $\therefore \lambda = \frac{h}{\sqrt{2mE}}$	Thorough understanding of these applications of physics. OR Partially correct mathematical solution to the given problems. AND / OR Partial understanding of these applications of physics.	(Partially) correct mathematical solution to the given problems AND / OR Reasonably thorough understanding of these applications of physics.	Correct mathematical solution to the given problems. AND Thorough understanding of these applications of physics.
(b)(i)	The intensity maxima and minima occur when the path difference from the two slits is an integral or half integral number of wavelengths, respectively. For intensity maxima: $\therefore d\sin\theta = n\lambda = \frac{nh}{p} = \frac{nh}{\sqrt{2mE}}$			
(ii)	For intensity minima: $\therefore d\sin\theta = \left(n-\frac{1}{2}\right)\lambda = \frac{\left(n-\frac{1}{2}\right)h}{p} = \frac{\left(n-\frac{1}{2}\right)h}{\sqrt{2mE}}$			
(c)	The fringes of intensity maxima are poorly defined because their positions depend on the wavelength. A spread of energies implies a spread of wavelengths which implies a spread of positions.			
(d)	For order 1, the extreme (outer) angle ($ø_1$) is given by $\sin\phi_1 = \frac{h}{d\sqrt{2m\left(E-\Delta E\right)}}$ For order 2, the extreme (inner) angle ($ø_2$) is given by $\sin\phi_2 = \frac{2h}{d\sqrt{2m\left(E+\Delta E\right)}}$ At overlap, sin $ø_1$ = sin $ø_2$ $\frac{h}{d\sqrt{2m\left(E-\Delta E\right)}} = \frac{2h}{d\sqrt{2m\left(E+\Delta E\right)}}$ $\sqrt{2m\left(E+\Delta E\right)} = 2\sqrt{2m\left(E-\Delta E\right)}$ $2m\left(E+\Delta E\right) = 8m\left(E-\Delta E\right)$ $E + \Delta E = 4E - 4\Delta E$ $5\Delta E = 3E$ $\Delta E = \frac{3E}{5}$ $\Delta E \le \frac{3E}{5}$			