Test: Atoms and Relativity

X-rays, Structure of the Atom, Standard Model, Relativity

1.

(a)

(i) Provides the electrons to be accelerated across the tube.

(ii) Conducts heat away from the target.

(b) Electrons have kinetic energy E_K

A photon's frequency is related to its energy by $E = hf$

Maximum frequency photon occurs when all the electron's kinetic energy is converted to a photon

$\therefore E_K = hf_{max}$

$\therefore f_{max} = \frac{E_K}{h}$

The electrons have kinetic energy E_K due to the work done by the large potential difference, $W = q\Delta V$

$\therefore E_K = q\Delta V = e\Delta V \quad \{\text{since charge on an electron is } e = 1.60\times10^{-19}\}$

$\therefore f_{max} = \frac{e\Delta V}{h}$

(c) $f_{max} = \frac{e\Delta V}{h}$

$$\lambda_{min} = \frac{c}{f_{max}} = \frac{hc}{e\Delta V} = \frac{6.63\times10^{-34}\times3.00\times10^{8}}{1.6\times10^{-19}\times100\times10^{3}} = 1.24\times10^{-11} \text{ m}$$

(d) Increasing the potential difference would increase the work done accelerating the electrons across the tube, so they would strike the target with more kinetic energy. This would increase the energy and therefore frequency of X-ray photons emitted, which means the X-rays would have greater penetrating power.

(e) Absorption and scattering of the X-ray photons.

(f) Attenuation will be greater in bone than soft tissue, because bone has greater density and a larger effective atomic number.

2.

Tungsten would be suitable because it has a high melting point compared to the other metals in the table. This is necessary because most of the electrons' kinetic energy is transformed into heat when it strikes the target in an X-ray tube, so another target metal could melt too easily.

When the electron is incident on the target, the distance from the electron to the nearest nucleus in the target material determines the amount of deceleration and therefore frequencies. Since there is a continuous range of possible distances, there is a continuous range of frequencies. The characteristic frequencies are produced when the incident electrons collide with electrons in the inner energy levels of the atoms of the target metal. The discrete energy level transitions that occur because of these collisions emit X-ray photons of specific frequencies.

3.

(a) The line emission spectrum is unique to the element because each atom of an element has discrete energy levels specific to that element.

(b)

(i) D

(ii) $\Delta E = 12.75 - 10.20 = 2.55 \text{ eV} = 4.08 \times 10^{-19} \text{ J}$

$E = hf$

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

$\therefore \lambda = \frac{hc}{E} = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{4.08 \times 10^{-19}} = 4.88 \times 10^{-7} \text{ m}$

(c)

(i) (any two upwards transitions beginning at n=1)

(ii) 13.60 eV

(iii) At room temperature, hydrogen atoms are in the ground state. There is not enough energy in the visible photons to excite the hydrogen atom from ground state to a higher energy state.

(iv) The sun's atmosphere is very hot so the hydrogen gas present in it can be excited above the ground state. Transitions from the n=2 state upwards correspond to frequencies of visible light, allowing absorption to occur.

(d) As the temperature increases, more and more higher frequencies are observed and all frequencies increase in intensity.

(e) Fluorescence is when an atom is raised to an excited state by absorbing a high-energy photon then emits the energy as a number of lower-energy photon by undergoing a number of smaller transitions to return to ground state.

4.

(a) Both occur when the atom is in an excited state. However spontaneous emission occurs immediately with no other cause needed whereas stimulated emission requires an incident photon.

(b) A metastable state allows some atoms to stay in an excited state for a period of time, rather than immediately returning to ground state. This allows more atoms to be present in higher-energy state than in ground state, which is a population inversion.

(c) A population inversion allows stimulated emission to predominate over absorption, so that the light is amplified, meaning an increasing number of photons with the same direction and phase.

(d) (Any of the following: coherent, monochromatic, high intensity and unidirectional.)

(e) (Any of the following: protective eye glasses that block the wavelength of the laser, protective gloves if using industrial lasers, avoid highly reflective surfaces, not use in a dark environment, not direct the beam towards eyes)

5.

(a) $up + down + charm$

$\therefore \tfrac{2}{3} - \tfrac{1}{3} + \tfrac{2}{3} = 1$

$\therefore \Lambda^{+}$

(b)

(i) Every baryon has exactly three quarks.

(ii) (Either strange or bottom)

(c)

(i) $\Lambda^{0} \rightarrow p^{+} + \pi$

1 → 1 + 0

(one baryon on the left, one baryon on the right, so baryon number is conserved)

(ii) -1

(iii) meson

(d) weak interaction

(e) Each photon has energy equivalent to half the total mass.

Lambda and antilambda baryons have equal mass, so half total mass is the rest mass of a lambda baryon.

$E = \Delta m c^{2}$

$$\therefore \Delta m = \frac{E}{c^{2}} = \frac{1.8\times10^{-10}}{\left(3.00\times10^{8}\right)^{2}} = 2.0\times10^{-27}\ \text{kg}$$

6.

The experiment results were reported by the media after being published, but prior to having been verified by other scientists. The importance of clear communication is shown here because it is possible for unverified results to be misrepresented or misunderstood by the public. It is also important for scientists to clearly communicate where results are unexpected or unusual, so that other scientists can make their own investigations.

The reliance of science on review and verification of results is shown here by this example illustrating that experimental results are not immune to error. If reliable conclusions are to be drawn from data, it is important that the results are able to be replicated and/or independently analysed to ensure the data is not inaccurate.

7.

(a) Mercury moves closer to Swift Justice over time until it arrives at the location of the craft.

(b) $t = \gamma t_0$

$$\therefore t = \frac{t_0}{\sqrt{1-\left(\frac{v}{c}\right)^2}}$$

$$\therefore \sqrt{1-\left(\frac{v}{c}\right)^2} = \frac{t_0}{t}$$

$$\therefore \left(\frac{v}{c}\right)^2 = 1-\left(\frac{t_0}{t}\right)^2$$

$$\therefore \frac{v}{c} = \sqrt{1-\left(\frac{t_0}{t}\right)^2} = \sqrt{1-\left(\frac{816}{873}\right)^2} = 0.355$$

8.

(c) $l = \frac{l_0}{\gamma}$

$$\therefore \gamma = \frac{l_0}{l} = \frac{0.59}{0.26} = 2.3 \quad (2.27)$$

(d) $v = \frac{s}{t} = \frac{0.59}{2.2\times10^{-9}} = 2.7\times10^{8}\ \text{ms}^{-1}$

$$p = \gamma m_0 v = 2.27\times1.8\times10^{-8}\times2.7\times10^{8} = 11\ \text{kgms}^{-1}$$