CHAPTER 15

More on the models of the atoms

Answers to revision questions

1. The phenomenon where a substance can behave as a wave and a particle at the same time is known as wave-particle duality.

2. Any particle that has a momentum can have a wavelength according to the equation $\lambda = \frac{h}{mv}$ and can therefore behave like a wave. This is particularly true for small particles like electrons.

3. (a) Using:

$$\lambda = \frac{h}{mv}$$
$$h = 6.626 \times 10^{-34}$$
$$m = 20\,\text{g} = 0.02\ \text{kg}$$
$$v = 2\ \text{m s}^{-1}$$
$$\lambda = ?$$
$$\lambda = \frac{6.626 \times 10^{-34}}{0.02 \times 2}$$
$$= 1.66 \times 10^{-32}\ \text{m}$$

(b) Using:

$$\lambda = \frac{h}{mv}$$
$$h = 6.626 \times 10^{-34}$$
$$m = 1.673 \times 10^{-27}\ \text{kg}$$
$$v = 3000\ \text{m s}^{-1}$$
$$\lambda = ?$$
$$\lambda = \frac{6.626 \times 10^{-34}}{1.673 \times 10^{-27} \times 3000}$$
$$= 1.32 \times 10^{-10}\ \text{m}$$

(c) Using $\lambda = \frac{h}{mv} = \frac{c}{f}$, since $c = \lambda f$

$$h = 6.626 \times 10^{-34}$$
$$m = 1.675 \times 10^{-27}\ \text{kg}$$
$$v = 5360\ \text{m s}^{-1}$$
$$c = 3 \times 10^{8}\ \text{m s}^{-1}$$
$$f = ?$$
$$f = \frac{3 \times 10^{8} \times 1.675 \times 10^{-27} \times 5360}{6.626 \times 10^{-34}}$$
$$= 4.06 \times 10^{18}\ \text{Hz}$$

4. (a) The electron travels from the right to left inside the CRT.

(b) In order to calculate the wavelength, we need to first determine the momentum and thus the velocity of the particle. The velocity can be calculated by equating the kinetic energy equation and the electrical energy equation, since the kinetic energy is derived from the electrical energy. That is:

$$E_k = E_E$$

$$\frac{1}{2}mv^2 = qV$$

$$V = 32\text{ V}$$

$$q = 1.6\times10^{-19}\text{ c}$$

$$m = 9.11\times10^{-31}\text{ kg}$$

$$v = ?$$

$$v = \sqrt{\frac{1.6\times10^{-19}\times32\times2}{9.11\times10^{-31}}}$$

$$v = 3.35\times10^{6}\text{ m s}^{-1}$$

Using:

$$\lambda = \frac{h}{mv}$$

$$h = 6.626\times10^{-34}$$

$$m = 9.11\times10^{-31}\text{ kg}$$

$$v = 3.35\times10^{6}\text{ m s}^{-1}$$

$$\lambda = ?$$

$$\lambda = \frac{6.626\times10^{-34}}{(9.11\times10^{-31})\times(3.35\times10^{6})}$$

$$= 2.17\times10^{-10}\text{ m}$$

(c) Using:

$$\lambda = \frac{h}{mv} \Rightarrow v = \frac{h}{m\lambda}$$

$$h = 6.626\times10^{-34}$$

$$m = 9.11\times10^{-31}\text{ kg}$$

$$\lambda = 1.32\times10^{-10}\text{ m}$$

$$v = ?$$

$$v = \frac{6.626\times10^{-34}}{(9.11\times10^{-31})\times(1.32\times10^{-10})}$$

$$= 5.51\times10^{6}\text{ m s}^{-1}$$

The kinetic energy is derived from the electrical energy supplied by the voltage.

$$\frac{1}{2}mv^2 = qV$$

$$m = 9.11\times10^{-31}\text{ kg}$$

$$v = 5.51\times10^{6}\text{ m s}^{-1}$$

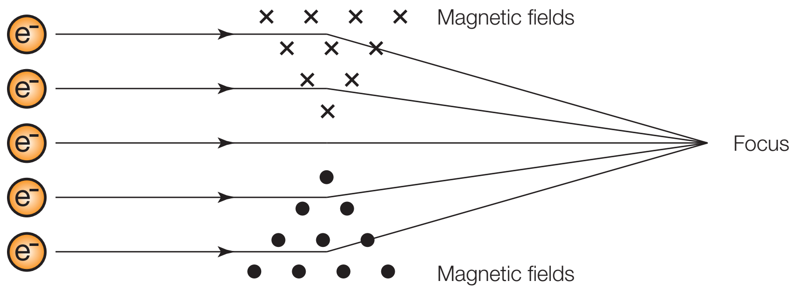
$$q = 1.6\times10^{-19}\text{ c}$$

$$V = ?$$

$$V = \frac{1}{2}\times\frac{9.11\times10^{-31}\times(5.51\times10^{6})^2}{1.6\times10^{-19}}$$

$$= 86.4\text{ V}$$

5. (a)



Note there are more magnetic field lines at the periphery. This results in stronger magnetic fields, and hence larger deflections. This is because the electron beams that are further away from the central beam need to be deflected more in order to be brought to the focus.

(b) Using:

$$\lambda = \frac{h}{mv} \Rightarrow v = \frac{h}{m\lambda}$$
$$h = 6.626 \times 10^{-34}$$
$$m = 9.11 \times 10^{-31}\ \text{kg}$$
$$\lambda = 0.102\ \text{nm} = 1.02 \times 10^{-10}\ \text{m}$$
$$v = ?$$
$$v = \frac{6.626 \times 10^{-34}}{9.11 \times 10^{-31} \times 1.02 \times 10^{-10}} = 7.13 \times 10^{6}\ \text{m s}^{-1}$$

The kinetic energy is derived from the electrical energy supplied by the voltage.

$$\frac{1}{2}mv^2 = qV$$

$$m = 9.11 \times 10^{-31}\ \text{kg}$$
$$v = 7.13 \times 10^{6}\ \text{m s}^{-1}$$
$$q = 1.6 \times 10^{-19}\ \text{c}$$
$$V = ?$$
$$V = \frac{1}{2} \times \frac{9.11 \times 10^{-31} \times \left(7.13 \times 10^{6}\right)^2}{1.6 \times 10^{-19}}$$
$$V \approx 145\ \text{V}$$

(c) The wavelength of 0.102 nm is much smaller than that of visible light, which is in the range of a few hundreds of nanometres. A smaller wavelength allows the resolution of smaller objects (by avoiding diffraction).

6. Davisson and Germer fired energetic electrons towards a nickel crystal and studied the behaviour of these electrons as they scattered off the nickel surface (see Fig. 15.3). The returning (scattered) electrons would pass through the gaps between the nickel atoms, which act as 'slits' so diffraction would occur. Consequently, interference patterns would be formed by the returning electrons, and if a detector is run along the side of the nickel crystal, a series of maxima and minima of electron intensity should be detected.

Davisson and Germer in their experiment were able to observe a series of maxima and minima of the scattered electrons, thus proving the wave nature of electrons and hence the existence of matter waves. Furthermore, from the interference pattern, Davisson and

Germer were able to measure the wavelength of the electrons waves that could have caused this diffraction pattern. The value agreed with the wavelengths calculated by using de Broglie's equation, $\lambda = \frac{h}{mv}$.

7. (a) De Broglie stated that electrons can behave as waves and this is true of all electrons, including those found inside atoms. De Broglie went on to propose that the electrons in an atom behave like standing waves, which wrap around the nucleus in an integral number of wavelengths.

(b) With the electron wave model of the atoms, de Broglie was able to explain why electrons, when in their own energy level, are stable and do not emit EMR; in other words, de Broglie theoretically explained Bohr's first postulate: as electrons were now standing waves, they were no longer moving charges and hence would not emit radiation. Furthermore, standing waves would not propagate, and therefore were stable and would not lose any energy.

Second, de Broglie's electron wave model enabled a mathematical derivation for Bohr's third postulate, the quantisation of angular momentum, which Bohr proposed radically without any theoretical support.

8. (a) The exclusion principle states that no two electrons in the same atom can have all four quantum numbers the same.

(b)

Sodium atom	n	l	m_l	m_s
Electron 1	1	0	0	+ ½
Electron 2	1	0	0	– ½
Electron 3	2	0	0	+ ½
Electron 4	2	0	0	– ½
Electron 5	2	1	– 1	+ ½
Electron 6	2	1	– 1	– ½
Electron 7	2	1	0	+ ½
Electron 8	2	1	0	– ½
Electron 9	2	1	+ 1	+ ½
Electron 10	2	1	+ 1	– ½
Electron 11	3	0	0	+ ½

Argon atom	n	l	m_l	m_s
Electron 1	1	0	0	+ ½
Electron 2	1	0	0	– ½
Electron 3	2	0	0	+ ½
Electron 4	2	0	0	– ½
Electron 5	2	1	– 1	+ ½
Electron 6	2	1	– 1	– ½
Electron 7	2	1	0	+ ½
Electron 8	2	1	0	– ½
Electron 9	2	1	+ 1	+ ½
Electron 10	2	1	+ 1	– ½
Electron 11	3	0	0	+ ½
Electron 12	3	0	0	– ½
Electron 13	3	1	– 1	+ ½
Electron 14	3	1	– 1	– ½
Electron 15	3	1	0	+ ½
Electron 16	3	1	0	– ½
Electron 17	3	1	+ 1	+ ½
Electron 18	3	1	+ 1	– ½

From the above two tables, it is clear that no two electrons in this atom have all four quantum numbers the same. It also shows the fact that the second shell can only hold a maximum of eight electrons is a direct consequence of the exclusion principle.

Pauli's exclusion principle provided a very solid theoretical background for why electrons had to be configured in the way they were in atoms. The principle also explained the regularity of the periodic table and the reasons for the atoms' positions in the periodic table. Pauli's exclusion principle provided a further advancement comparing to Bohr's model in how to place electrons around the nucleus.

9. See Chapter 15.

10.

Year	Event
1897	J. J. Thomson proposed his 'plum-pudding' model of the atoms after measuring the charge to mass ratio of the cathode rays.
1911	E. Rutherford's discovery of the nucleus through the alpha scattering experiment.
1913	N. Bohr developed his theory of the model of atoms. It successfully explained the hydrogen emission spectrum.
1924	L. de Broglie proposed the existence of matter waves and the wave-model of the electrons around the atoms.
1925	W. Pauli proposed his exclusion principle to give a more detailed explanation of the electron configuration around the nucleus.
1927	C. Davisson and L. Germer experimentally proved the existence of matter waves.
1927	W. Heisenberg proposed the uncertainty principle for which he won the Nobel Prize.