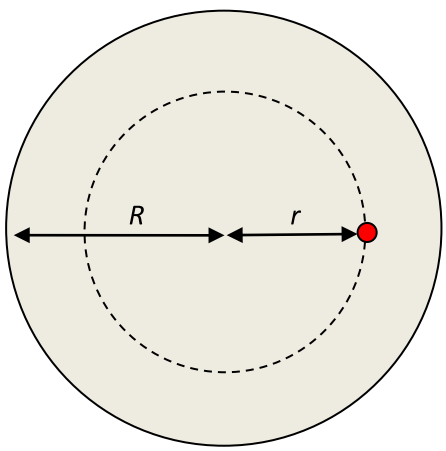
Teacher notes
Topic E

J. J. Thomson's model of the atom

After discovering the electron, J. J. Thomson constructed a model of the atom in which the atom's positive charge occupied the volume of the atom and electrons were embedded in this volume of positive charge.

This is the model that the Rutherford-Geiger-Marsden experiment challenged and rejected.

The diagram shows this model for hydrogen with the electron at a distance of *r* from the center.



It is a result of electricity that only the positive charge *within* the dotted line exerts a force on the electron. Let us find this force.

Assuming the positive charge to be uniformly distributed in the atomic volume, the charge within the dotted line is $e\frac{\frac{4\pi}{3}r^3}{\frac{4\pi}{3}R^3}=e\frac{r^3}{R^3}$. The force is then $F=\frac{1}{4\pi\varepsilon_0}\frac{(e\frac{r^3}{R^3})e}{r^2}=\frac{1}{4\pi\varepsilon_0}\frac{e^2}{R^3}r$. This force is directed towards the center of the sphere. Now, at the center, the force is zero, so this is the equilibrium position of the electron. So, we may consider that the electron, when a distance *r* from the center, has been displaced a distance *r* from its equilibrium position. The force just derived pulls the electron back towards the equilibrium position. Thus,

$$ma=-\frac{1}{4\pi\varepsilon_0}\frac{e^2}{R^3}r$$

And so

$$a = -\frac{1}{4\pi\varepsilon_0}\frac{e^2}{mR^3}r = -\omega^2 r \text{ where } \omega^2 = \frac{e^2}{4\pi\varepsilon_0 mR^3}.$$

But this is the equation of simple harmonic motion!

Thus, in the Thomson model, electrons oscillate within the volume of positive charge. But according to classical electromagnetic theory, an oscillating electric charge emits electromagnetic waves with a frequency equal to the oscillation frequency.

In other words, the atom would emit light (EM radiation). Could this be used to explain atomic emission spectra?

The answer is no for 2 reasons. The first is that this would give rise to just one emission frequency, and we know that hydrogen has many emission lines. The second reason is that the frequency is all wrong.

Let us calculate the frequency using an atom radius of 0.5×10^{-10} m.

$$\omega = \sqrt{\frac{e^2}{4\pi\varepsilon_0 mR^3}} = \sqrt{\frac{8.99\times 10^9 \times (1.6\times 10^{-19})^2}{9.1\times 10^{-31}\times (0.5\times 10^{-10})^3}} \approx 4.6\times 10^{16}\ \text{s}^{-1}.$$

Since $\omega = 2\pi f$ this means that $f = \frac{\omega}{2\pi} = \frac{4.5\times 10^{16}}{2\pi} \approx 7.2\times 10^{15}$ Hz or $\lambda = \frac{c}{f} = \frac{3\times 10^8}{7.2\times 10^{15}} \approx 4.2\times 10^{-8}$ m.

This is not a visible wavelength.

So, the Thomson model can be rejected also on theoretical grounds. It can also be rejected for other reasons as well: the positive charge is spread throughout the atomic volume. The charge in a small part of this volume would not be an integral multiple of the elementary charge so it violates charge quantization (which was of course was not known at the time). Also, this charge was assumed to be some kind of fluid so the electron, moving through it, would suffer a drag force which we have not considered. The drag force would have stopped the oscillations.