

# Workshop Tutorials for Introductory Physics

## Solutions to QI2: Atomic Structure

### A. Review of Basic Ideas:

#### The evolving model of the atom

The word “*atom*” comes from Greek, and means indivisible (*a-* not, *tom-* divisible). In about 450 BC Democritus postulated that **matter** was made up of tiny individual atoms, and that the **shape** of the atoms determined the properties of the material. It took more than another 2 millennia for this theory to be seriously advanced on.

The first modern model is Thompson’s plum **pudding** model. In this model the atom is described as a lump of material with a **uniform** positive charge and uniform low density, with little bits of negative charge (**electrons**) speckled throughout. Thompson measured the charge/mass ratio of the electron, the first sub-atomic particle. But even though this showed that the atom wasn’t quite **indivisible**, atoms weren’t renamed “*toms*”

The next big change to the model came from Rutherford. He discovered that the atom wasn’t a uniform lump, but actually had a little **nucleus** where the positive charge was, and the electrons were outside this. In fact, he showed that the nucleus was actually really small compared to the size of the atom. He suggested that the atom was like a **solar** system, with a nucleus in the middle like a sun, and electrons orbiting around like **planets**.

There were some problems with this model. But at about the same time Planck and others were developing the **quantum** theory. Bohr incorporated the quantum theory into Rutherford’s model, which solved a lot of the problems and explained not only why atoms show **spectra**, but predicted where the lines for hydrogen would be. Unfortunately it didn’t work very well for bigger atoms.

The currently accepted model of the atom is that the electrons exist in clouds around the nucleus, and have **discrete** energies which can be determined from quantum mechanics, although the calculations can be very difficult. While this model is bound to change a bit, it seems to work pretty well. In fact, all modern **electronics** is based on it. Everything that has a transistor in it, from a digital watch to a computer, is based on quantum mechanics and the quantum model of the atom.

### B. Activity Questions:

#### 1. Hydrogen Spectrum

- a. You should see a blue-ish coloured light.
- b. You should have seen lines of different colours, due to different electronic transitions. Discrete energies mean that electrons can only make distinct transition, hence they can only change energy by fixed amounts, hence they can only emit (or absorb) photons of particular energy.

#### 2. Emission spectra

The spectrum of any given element is unique, hence by observing the spectrum of a source, we can tell what elements are present. This is used to identify what elements are in all sorts of things, including stars.

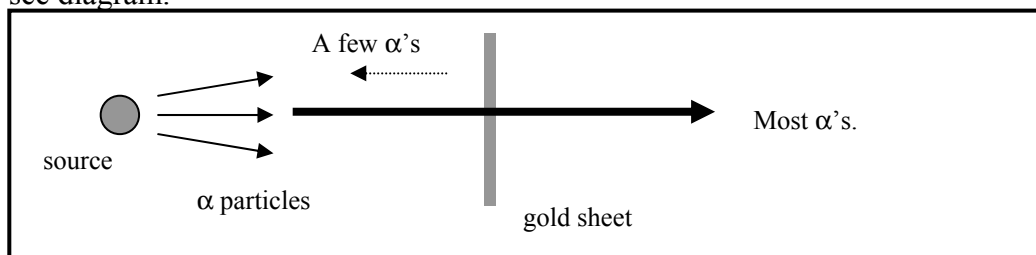
#### 3. Identify the element

The element contained in fluorescent lights is mercury.

### C. Qualitative Questions:

1. The Rutherford experiment.

a. and b. see diagram.



c. The nucleus is very small compared to the atom, and hence most of the  $\alpha$ 's pass straight through. Previously (the Thompson model) it was thought that the positive charge was distributed throughout the atom, hence Rutherford's surprise at the scattering of the massive  $\alpha$  particles.

d. Had Geiger accidentally used a neutron source there would have been very few particles scattered. Neutrons have no charge and only  $\frac{1}{4}$  the mass of an  $\alpha$  particle, hence interact only weakly with matter compared to the  $\alpha$  particles.

2.

a. Discrete means that the energy levels can only have certain values, there is not a continuous range of energies possible.

b. Light comes in discrete quanta, called photons, matter comes in discrete amounts, such as electrons and protons and neutrons. Information usually comes in discrete amounts as well, for example letters in words, 0's and 1's in computers and base pairs in DNA.

c. We know that there are discrete energy levels in atoms, because as photons are emitted from a certain atoms they can only have a particular set of wavelengths. The wavelengths are related to the energy of the photons by  $E = hc/\lambda$ . The energy of the photon is equal to the energy difference between two energy levels.

d. The energy levels for hydrogen and helium would be different because of the different numbers of electrons and also because of the different number of protons in the nucleus which attract the electrons.

e. The current model is the quantum mechanical model which is a mathematical model based on probability waves. This model can be visualised as a cloud of electrons surrounding the nucleus. This cloud gives the probability of finding an electron in a particular area, the densest part of the cloud has the highest probability of finding an electron in that area. The different shape and size of the electron clouds correspond to different energy levels.

### D. Quantitative Question:

The effective radius of a nucleus can be calculated using  $R = R_0 A^{1/3}$ , where  $R_0 = 1.2 \text{ fm} = 1.2 \times 10^{-15} \text{ m}$ , and  $A$  is the atomic mass number of the nucleus, 197 for gold.

a.  $R = R_0 A^{1/3} = 6.98 \times 10^{-15} \text{ m}$

b. Density = mass/volume =  $197 \times 1.66 \times 10^{-27} \text{ kg} / \pi \times 4/3 R^3 = 2.3 \times 10^{17} \text{ kg.m}^{-3}$ , very very dense!

A gold atom has an effective radius of around 2 nm. Imagine making a model of a sheet of atoms with nuclei 1cm in diameter (marbles, for example), and spacing them so that the atoms were just touching.

c. An atom is around  $10^{-10}/10^{-15} = 10^5 \times$  bigger than a nucleus. So if the nucleus is 1cm in diameter, the atom should be  $10^5 \times 1 \text{ cm} = 1 \text{ km}$  across!

d. It would be very hard to hit the nuclei with thrown marbles from several atomic radii away!