Discovery of the Atom – Questions and Answers

1. Early Greek philosophers like <u>Plato</u> and <u>Aristotle</u> taught that matter was continuous, meaning it <u>could</u> be divided endlessly into even smaller pieces. The first known written record that talks of matter being composed of atoms is attributed to <u>Democritus</u>. Leucippus and Democritus believed matter consisted of tiny particles that <u>couldn't</u> be divided into smaller pieces and that <u>nothing</u> occupied the space between the particles of matter. These early ideas about the structure of matter were based on <u>beliefs</u> or <u>philosophies</u> rather than experimental observations.

2. The French chemist Antoine-Laurent Lavoisier is credited with discovering the law of conservation of mass. Essentially this law states that there's no change in mass during a chemical reaction.

a) Complete the following sentence which is a restatement of the law of conservation of mass. In a chemical reaction the total mass of the products formed equals <u>the total mass of the reactants consumed</u>.

b) In what way was the development and proposal of Lavoisier's law of conservation of mass different to Democritus, proposing that matter consisted of invisible particles called "atomos"?

Democritus based his ideas off beliefs and philosophies and so didn't provide observational evidence to support his claims. Lavoisier conducted many experiments and collected data to support his claims of the law of conservation of mass.

3. The idea of compounds having a constant composition was not new before it had been proposed by Proust. Why was the "law of constant composition" credited to Proust?

Although Proust's law of definite proportions wasn't a new idea, he was the first to experimentally show the law. He provided compelling evidence that the previously assumed law was, in fact, consistent. Thus, he was credited with the law since he was the first to experimentally demonstrate it.

4. John Dalton is accredited with having proposed the original atomic theory of matter. He proposed for example, “All atoms of a given element are identical having the same size, mass and chemical properties”. How has our view of this point changed?

All atoms of a given element have the same chemical properties but not necessarily the same size and mass. Atoms of a given element can have differing numbers of neutrons. Elements like this are known as isotopes.

5. The invention of the cathode ray tube (CRT) in the mid-nineteenth century ultimately resulted in J.J Thompson’s discovery of the electron. Answer the following questions about the CRT.

a) How are cathode rays detected in a CRT?

The cathode rays cause a low-pressure gas inside the CRT to glow. The rays could also be detected as they cause phosphors such as ZnS to glow.

b) What observations led Thompson and others to conclude that cathode rays must have a negative charged?

The cathode rays are deflected towards a positively charged plate and away from a negatively charged plate, which led Thompson to believe that the cathode rays possessed a negative charge.

c) Thompson’s modified CRT used a narrow beam of cathode rays. Very briefly describe how he was able to produce a beam of cathode rays.

The cathode rays stream away from a high voltage negatively charged plate as a wide beam. The rays are attracted towards a distant positively charged plate with a narrow slit in it. The rays passing through the slit produce a narrow beam which is attracted to a more distant positively charged plate.

d) In Thompson’s modified CRT how did he “see” the cathode rays?

Thompson used a phosphor-coated screen which glowed when struck with cathode rays. This produced a trace that showed the path of the cathode rays.

e) What was Thompson able to determine about the cathode rays with his modified CRT?

Thompson was able to determine the mass to charge ratio of a cathode ray particle (now known to be an electron). He estimated the mass of the cathode ray particle to be less than 1/1000 the mass of the lightest known element.

6. Ernest Rutherford and his co-workers carried out a series of experiments in which a beam of alpha particles were targeted at a very thin sheet of gold foil only a few atoms thick.

a) What are alpha particles and where did Rutherford get them?

Alpha particles are produced by naturally occurring (or artificial) radioisotopes (Rutherford used radium). They're fast-moving helium nuclei with a +2 charge.

b) What physical property of gold allowed it to be made so thin?

Gold is a very malleable metal and thus can be made into very thin sheets.

c) If Thompson's model of the atom was correct, what did Rutherford and his co-workers expect to observe?

Based on Thompson's model of the atom with a uniformly spread mass and charge, Rutherford hypothesized that the alpha particles should essentially pass through the gold sheet undeflected.

d) How were the deflected alpha particles counted in these experiments?

Rutherford used a zinc sulfide coated screen and a microscope to count the flashes produced by the alpha particles striking the fluorescent screen.

e) Why was Rutherford and his team so surprised with their observations? What did Rutherford interpret this to mean about the structure of the atom?

Some alpha particles were considerably deflected. Rutherford interpreted this to mean that there must be a very small, high mass and high charge central nucleus in an atom and that it takes up a very small percentage of the atom's volume. This nucleus was causing the occasional alpha particle to be deflected.

7. Rutherford's model of the atom worked quite well as it was able to explain many of the observed properties of matter. However, Rutherford and his co-workers were aware of several shortfalls. In particular, it appeared his model could only account for about half the mass of the atom. What type of particle did Rutherford suggest was missing? Why was it so hard to detect it and who is credited with its discovery?

Rutherford suggested that the missing mass was due to an undetected neutral particle. It was difficult to detect because it had no charge and the detectors used at the time relied on charged plates to identify such particles. Sir James Chadwick was credited with its discovery, which he later called the neutron.

8. Niels Bohr made some important modifications to the Rutherford model of the atom. His modifications enabled the stability of the atom to be accounted for as well as explain line spectra (emission spectra).

a) Explain why the Rutherford model meant that the atom was inherently unstable.

Rutherford's idea of electrons orbiting the nucleus meant that such orbiting electrons would, according to classical physics principles, continuously emit radiation, causing the electron to lose energy and speed and presumably spiral into the nucleus, hence being inherently unstable.

b) What did Bohr propose about the arrangement and energy of the electrons in an atom that solved the problem of its instability?

Bohr proposed that the electrons could only orbit at specific radii, which were associated with fixed amounts of quanta energy, and so they couldn't just lose energy and spiral into the nucleus.

c) What simple instrument can be used to observe the various colours (spectrum) produced by a discharge tube?

A spectroscope.

d) Describe the visible part of the emission spectrum of hydrogen gas.

The visible part of the emission spectrum of hydrogen gas consists of 4 distinct lines of light of different colours: red, cyan, violet and blue. There's no light (black) between the colours.

e) Using the Bohr model of the atom, explain how a gas like hydrogen can produce a line spectrum (emission spectrum) that has only a few specific wavelengths of light.

Once a hydrogen electron is excited, it's in a higher energy level than normal. When it falls back to a lower energy level, it emits a photon of light of a specific wavelength or colour of light. There are several different visible colours possible for hydrogen depending on the specific electron transitions involved. Only certain quanta of allowable electron energy are possible and hence only certain specific energy photons (colours) can be produced.