Competitive Exams: Thermodynamics

Cartesian Diver

A Cartesian diver is a classic science experiment, named for Rene Descartes, in which an eye dropper or other container open only at the bottom (the "diver") is placed in a much larger container with flexible walls, such as a 2 liter soft drink bottle, and adjusted so it barely floats at the top of the water in the larger container.

When the larger container is squeezed, the air inside the diver is compressed, reducing the overall displacement or buoyancy of the diver, which then sinks. One reason for using an eye dropper is that air cannot readily escape the end of the dropper, due to surface tension, however a pen cap can also be used:

You will need: Modelling clay; plastic pen cap; glass; water; paper clips; plastic drinks bottle with lid.

1. Fix a lump of modelling clay to the end of the plastic pen cap. Adjust the amount of clay until the top of the cap just floats above the surface in a glass of water. A bubble of air trapped inside the cap makes it light enough to float.
2. Seal any holes in the tip of the pen cap with modelling clay.
3. Use paper clips to make a hook and weights. Now put your diver into a full bottle of water and screw on the lid.
4. Gently squeeze the bottle. The diver sinks as extra water pushes into the pen cap, forcing the air bubble to shrink. The diver is now too heavy to float.
5. Release the bottle. The diver rises as the extra water leaves the cap, making it light enough to float again. Experiment with the number of paper clips to see how the extra weight affects your diver.

Expansion with Heat

Gases expand a lot when they're heated, and contract a lot when cooled. You can easily demonstrate this in a simple experiment.

To Experiment: Plastic bottle; a glass beaker or any other large container; a balloon; hot water from the hot tap (do not use boiling water) ; ice.

- At room temperature, stretch the neck of a balloon over the mouth of a bottle. The balloon will hang down limply. Now place the bottle in a large beaker of hot water. The limp balloon starts inflating and eventually stands upright as the air inside the bottle expands.
- Now place the bottle in a beaker of ice and water. The balloon immediately starts deflating, and may eventually be drawn into the neck of the bottle. This happens because the air in the bottle has cooled and contracted.

Subatomic Particles

At first, scientists thought that atoms were rather like billiard balls-solid objects with no internal structure. But further experiments showed that atoms were made of subatomic particles. And further experiments still have shown that even these particles have structure …

The three particles that make up atoms are protons, neutrons, and electrons. Protons and neutrons are heavier than electrons and reside in the nucleus, which is the center of the atom. Protons have a positive electrical charge, and neutrons have no electrical charge. Electrons are extremely lightweight and are negatively charged. They exist in a cloud that surrounds the atom. The electron cloud has a radius 10,000 times greater than the nucleus.

The first subatomic particle to be identified was the electron, in 1898. Ten years later, Ernest Rutherford discovered that atoms have a very dense nucleus, which contains protons. In 1932, James Chadwick discovered the neutron, another particle located within the nucleus.

Rutherford performed early experiments of shooting alpha particles (helium nuclei) at sheets of gold to show that atoms were, in fact, mostly empty space. Some of the alpha particles passed through the foil as expected, but some particles bounced back.

This model basically looks like a little solar system, where the nucleus is the Sun and the electrons orbit the nucleus like the planets orbit the Sun.

The solid behavior of atoms is due to the electromagnetic repulsion of the electrons in the outer orbits. When you strike your hand on a table, the solidness you feel is an illusion caused by the electrons pushing away from the atoms of the table and the atoms of your hand.

Alpha particles carry positive charge. Like charges repel and opposites attract. This meant that there was a small concentration of positive charges in the atom. Rutherford’s model of an atom has a small

- nucleus containing
- protons (positive charged particles)
- neutrons (particles with no electric charge) surrounded by

- electrons (small particles with negative charge) .

Chemical Bonding

Chemically bonding occurs when two atoms can exchange or combine their outer electrons in such a way that is “energetically favorable” An energetically favorable state can be seen as similar to the way a dropped rock has a natural tendency to fall to the floor. When two atoms are close to each other and their electrons are of the correct type, it is more energetically favorable for them to come together and share electrons (become “bonded”) than it is for them to exist as individual, separate atoms. When the bond occurs, the atoms become a compound. Like the rock falling to the floor, they “fall” together naturally.

The Nucleus

The nucleus of an atom is made up of positively-charged protons, and a similar number of neutrons (with no electrical charge) . It is held together by the tight pull of what is known to chemists and physicists as the strong force. This force between the protons and neutrons overcomes the repulsive electrical force that would, according to the rules of electricity, push the protons apart otherwise. Protons and neutrons are 1,860 times heavier than electrons. Virtually all the mass of the atom resides in the nucleus.

The nucleus is only $\frac{1}{100}$, 000^{th} the diameter of the atom (like the size of a baseball compared to that of a ball park) and yet nearly all the mass of the atom is in that tiny nucleus.

There are just over one-hundred elements. Each element may also have several isotopes (different numbers of neutrons) , but generally only a few will be stable (not radioactive) . Heavy atoms tend to be radioactive.

Normally, the number of electrons and protons is the same, and since the electrical charges on electrons and protons is equal but opposite, the atom has no net electrical charge (except in the cases mentioned) . The number of protons determines which chemical element the atom belongs to:

Electrons

Electrons are negatively charged subatomic particles, and they cause electricity when they flow, or static electricity when many of them build up in one place, or are taken away.

The electrons have negative electrical charge, and their movement between atoms is responsible for electrical current. They can also be removed from atoms by rubbing different materials together, e. g. By combing your hair (try holding the charged comb near a thin trickle of water from a tap) . This is static electricity.

The electrical charge of protons and electrons are exactly equal but opposite. Usually there are the same number of protons and electrons in an atom, and their electrical charges cancel each other.

The electron is the lightweight particle that "orbits" outside of the atomic nucleus. Electrons surround the atom in pathways called orbitals. The inner orbitals surrounding the atom are spherical but the outer orbitals are much more complicated.