Ionization and excitation

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Collisions of electrons with atoms

When electrons collide with atoms, what happen depends on the speed (and therefore the kinetic energy) of the electron. At very low energies, the electron will collide elastically with the atoms, i.e. they will bounce off without losing any energy. As the energy is increased, inelastic collisions start to occur, and the electrons stand a chance of losing energy to the atom, changing its atomic structure in the process.

Ionization

An ion is a charged atom, one which has gained or lost one (or more) electrons, so that the number of electrons no longer equals the number of protons, as it does in a neutral atom. We have already seen that in a metal, most of the atoms have at least one electron which can move freely around the metal, leaving them as positive ions. Atoms can become ionized by gaining or losing electrons in lots of different ways, including chemical bonding (and in particular ionic bonding); having their electrons knocked out by passing alpha, beta or gamma radiation; decaying themselves by α or β decay; having their electrons annihilated by positrons; or being subjected to a too strong electric or magnetic fields.

A *plasma* is an ionized gas: a gas made up partly or completely of charged particles like ions[1]. We most often encounter such a gas when electrons pass through a gas, with enough energy to knock electrons out of the gas atoms and make them into ions.

The energies required are often measured in electronvolts. The electronvolt (eV) is a unit of energy, equal to the energy an electron has gained when it has moved through a potential difference of one volt. Since the work done when a particle of change Q moves through a potential V is $E = QV$, an electron with $Q = 1.6 \times 10^{-19}\,\mathrm{C}$ will gain $1.6 \times 10^{-19}\,\mathrm{J}$ of (kinetic) energy when it is accelerated through a p.d. of $1\,\mathrm{V}$. At first

[1]Most astrophysicists think that 99.9% of all observable matter is in the form of plasma.

this may seem an odd unit of energy to use, but it is most useful when dealing with energies on an atomic scale.

$$1\,\mathrm{eV} = 1.6 \times 10^{-19}\,\mathrm{J}.$$

The minimum amount of energy that is needed to ionize an atom (i.e. to remove its most loosely bound electron) is known as the *ionization energy*. For example, the ionization energy of hydrogen is 13.6 eV (or 2.18×10^{-18} J). Of course, hydrogen only has one electron, but for other elements, we could go on removing electrons. The energy needed to remove the next most loosely bound electron is called the second ionization energy, and so on…

We can see from the definition of the electron volt that 13.6 eV is the kinetic energy gained by an electron when it is accelerated through a p.d. of 13.6 V. Therefore, if an electron which has been accelerated from rest through a p.d. of 13.6 eV collides with a hydrogen atom, it has exactly the right amount of energy to knock the hydrogen's electron out of the atom and leave the hydrogen ionized. This in fact is a common way to produce ionized gases in the laboratory, via a low pressure gas between electrodes in a long narrow glass tube, and such an arrangement is known as a discharge tube. The ionized gas glows a characteristic colour, for reasons we shall discover when we discuss line spectra.

Excitation

Gas atoms can still absorb energy from electrons without being ionized. In fact, even if the incoming electron does not have enough energy to completely remove an electron (and the easiest electron to remove is the most loosely bound one), it might be able to 'excite' the atom by giving one of its electrons some energy. The excited electron can then move into a higher energy state (one which is further from the nucleus).

For example, the first and second *excitation energies* of hydrogen are 10.2 eV and 12.1 eV respectively. An energetic incoming electron striking a hydrogen atom might bounce off elastically, losing no energy; it might excite the hydrogen atom, losing one of these amounts of energy doing so; or it might ionize the hydrogen atom completely, losing 13.6 eV of energy. There will be a certain probability of each occurring.