THERMONIC EMISSION AND RADIOACTIVITY

THERMONIC EMISSION

In an atom, electrons revolve around the nucleus. The electrons in the inner orbits are strongly attracted by the nucleus, and hence, they are called “bound electrons”. However, the attractive force of the nucleus on the electrons revolving in the outermost orbit is weak. In metals, the outer most electrons are not bound to a particular atom. Though they are within the boundaries of the metal, these electrons are free to move throughout the body. These are called “free electrons” or “conduction electrons”. Can these free electrons come out of the metal surface? If an electron leaves the surface, the metallic body becomes positively charged and attracts the electron back to the surface. In order to escape from the metal surface, an electron needs sufficient kinetic energy. If the kinetic energy is less, the electron is attracted back to the metal surface. The electron is able to escape from the metal surface only when it has kinetic energy sufficient to overcome the electrostatic attractive force. With a little more kinetic energy, the electron moves farther away but is still attracted back to the metal surface.

The energy required by the electron can be provided in different ways. When a metal surface is heated, the “electrons” escape from the surface of the metal. This phenomenon is known as “thermionic emission” and the electrons thus emitted are called “thermions”. If the electrons are emitted by a metal surface after absorbing “light energy”, then the phenomenon is called the “photoelectric effect” and the electrons thus emitted are called “photoelectrons”.

Minimum Energy Required to Emit an Electron

Different elements require different amount of energies to emit an electron. The minimum amount of heat energy required to emit an electron from a metallic surface is called “threshold energy” or “work function”. Usually work function is expressed in “electron volt (eV)”, e.g., the work function for Tungsten is 4.52 eV and 1 eV = 1.6 x 10^{-19}J.

Work Functions of Some Common Elements

Element	Work Function (eV)
Silver	4.7
Chromium	4.5
Gold	5.3
Copper	4.8
Zinc	3.8
Calcium	2.8
Barium	2.6
Magnesium	3.7

Thermionic Emission

Thermionic emission was first observed by Thomas Alva Edison while trying to find the reason for the breakage of filaments and uneven blackening of his incandescent bulbs. His observation of the emission of charged ions from a red-hot filament has come to be known as the “Edison Effect’”. To understand these charged ions better, Edison placed a metallic plate in his bulb and connected it externally to a battery through a galvanometer. The filament got heated when current was allowed to pass through it. He observed a deflection in the galvanometer when the metallic plate was connected to the positive terminal of the battery and no deflection when it was connected to the negative end of the battery. The charged ions emitted from the red-hot filament of the bulb were actually ‘electrons’ which were subsequently discovered by J.J. Thomson. This fact of the emission of electrons from a heated filament is used in many applications of electronics like the “diode valve” and the “cathode ray tube”.

Thermionic Diode Valve

A diode is an electronic device that conducts electric current in only one direction. J. A. Fleming developed the first thermionic diode that works on the basis of thermionic emission.

Working of A Diode Valve

A low tension battery is connected to the two ends of a filament. When current is passed, the filament gets heated. A small region around the cathode with excess free thermions is called “space charge”. When a metallic plate is connected to the positive terminal of a high-tension battery, it behaves like an anode and attracts electrons or thermions from the cathode and current starts flowing between the two electrodes. This current is unidirectional and can be controlled by varying the voltage of the high-tension battery.

In thermionic emission, the measure of the number of thermions emitted per second is called the rate of thermionic emission. The following factors influence the rate of thermionic emission.

1. It depends on the nature of the metal surface. It is inversely proportional to the work function of the metal used.
2. The rate of thermionic emission is directly proportional to the temperature of the surface.
3. It is also directly proportional to the area of the surface.

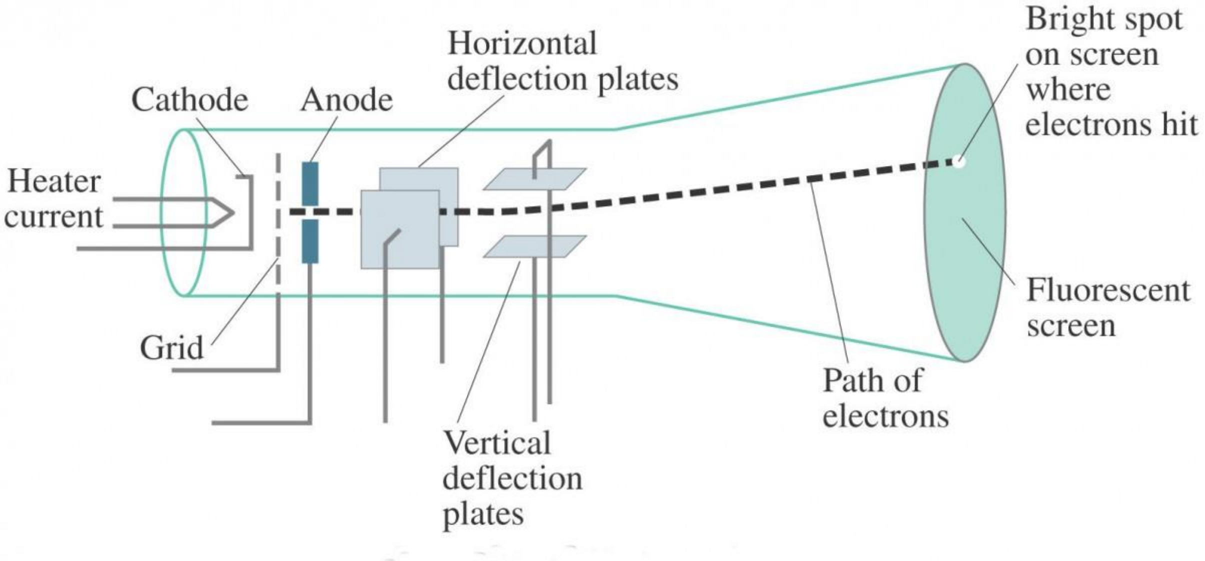
The material that is used as a thermionic emitter must have a low work function and a high melting point.

Some Most Useful Thermionic Emitters

Tungsten: It has a high melting point of 3660 K and starts emitting thermions at 2500 K. It has a high work function of 4.52 eV.
Thoriated Tungsten: Tungsten is coated with Thorium and Carbon. This starts emitting electrons from 2000 K and its work function is 2.6 eV.

CATHODE RAY TUBE

The picture tube of the TV is a Cathode Ray Tube or CRT, an instrument that converts the input electrical signals into the output visual signals. It is also known as an oscilloscope. It is made up of three major assemblies: 1. Electron Gun, 2. Deflecting Plates and 3. Fluorescent Screen. These three assemblies are placed in a long hollow evacuated glass tube.



The electron gun has a tungsten filament, two batteries, one low tension and one high tension, a switch, variable resistance, cathode plate, control grid, and double anode cylinders. The deflecting plates consist of two pairs of flat plates. One pair of plates is kept horizontal. These are called Y- plates. The other pair of plates is placed vertical. These are called X – plates. All the plates are kept with their planes parallel to the electron beam. The fluorescent screen is a flat glass plate placed at the end of the tube. Its inside surface is coated with a fluorescent material.

Working of a CRT

When the switch is in the ON position, direct current passes through the tungsten filament which is kept in series with the variable resistance. As the strength of the current is increased, the temperature of the filament increases. The strength of the current in the series circuit is adjusted using the variable resistance. The tungsten filament turns red hot and maintains the required steady temperature. The heat generated by the red hot tungsten filament is transferred to the cathode plate. As the cathode plate is coated with oxides of barium or strontium, it starts emitting thermions on getting heated up.

The number of thermions generated depends on the temperature of the cathode plate, which in turn is dependent upon the temperature of the tungsten filament. These thermions get attracted by the anode. They accelerate due to the high potential difference between the cathode and the anode. In between the cathode and anode there is control grid. This control grid is made of extremely fine wire gauze. The electric signal, which is the input to the CRT, are fed to this grid. The brightness of pattern, which is the output of the CRT, on the screen is controlled by varying the negative potential on the grid with respect to the cathode. The thermions come out of the hole in the anode in the form of a fine beam.

When a potential difference is applied across any pair of plates, an electric field is set up between the plates. Due to this electric field the electron beam gets deflected. The Y – plates deflect the beam in the vertical direction, while the X – plates deflect the beam in the horizontal direction. The electron beam on striking the screen gives a bright spot thus converting the passing electrical signal into the visual pattern observed on screen. The bright spot is due to the coating of fluorescent material on the screen.

CRTs are used for:

1. Investigating the wave form of an unknown AC voltage.
2. Determination of frequency of AC voltage
3. Checking the wave form of any electrical signal
4. Displaying the visuals in televisions

ISOTOPES AND ISOBARS AND ISOTONES

The nucleus of an atom is composed of elementary particles, called protons and neutrons. Protons and neutrons are collectively called nucleons. Protons are positively charged particles. The mass of a proton M_p = 1.00727 amu = 1.67292 x 10^{-27} kg. Neutrons are electrically neutral, and the mass of each neutron is equal to 1.00866 amu = 1.6749 x 10^{-7} kg.

The nuclides of an element are shown by the notation $_Z X^A$. Here, X is the chemical symbol of the element, and Z is its atomic number. The number of protons in the nucleus of an atom is called its atomic number. Finally, A is the mass number of the element, and represents the total number of protons and neutrons in its atom. The value (A – Z) gives the number of neutrons of an element.

For example, $_6C^{14}$, which is the nucleus of the carbon atom with mass number 14 and atomic number 6. It means that in the nucleus of a $_7N^{14}$ atom, the sum of the number of protons and neutrons is 14. Out of the 14 nucleons, the number of protons is seven. The atomic mass of an element, shown in the periodic table, when expressed in atomic mass units, is usually very close to its mass number. However, there are several exceptions. For example, the atomic mass of the chlorine atom is 35.46 amu, whereas its atomic mass number is 34. Accurate measurements of atomic masses, carried out with a device known as a mass spectrometer reveal the existence of different types of atoms of the same element, which exhibit the same chemical properties, but differ in their masses. This was first observed in neon. Three different kinds of neon atoms exist with their masses very close to the integer numbers 20, 21 and 22. On further studies, it was found that the difference in masses was because of the different number of neutrons present in their nuclei.

Isotopes

Atoms of the same element with the same atomic number but different mass numbers are called isotopes of that element. The three neon isotopes are represented by ${}_{10}Ne^{20}$, ${}_{10}Ne^{21}$ and ${}_{10}Ne^{22}$. Many elements have naturally available isotopes. Hydrogen has three isotopes, namely hydrogen, deuterium and tritium, represented by ${}_{1}H^{1}$, ${}_{1}H^{2}$ and ${}_{1}H^{3}$ respectively. Note that the isotope tritium is not available naturally but is produced artificially in laboratory. Oxygen also has three isotopes, known as ${}_{8}O^{16}$, ${}_{8}O^{17}$ and ${}_{8}O^{18}$. The number of protons and electrons is the same in all the isotopes of an element. Hence, they all have identical chemical behaviour. Obviously, the isotopes of an element will have different number of neutrons, because of which the atomic mass number differs. Note that the atomic mass or atomic weight of an element shown in the periodic table is the statistical or weighted average of the atomic weights of its isotopes.

Isobars

Now, look at these three nuclei $_{19}K^{39}$, $_{19}K^{40}$ and $_{20}Ca^{40}$. The nuclei $_{19}K^{39}$ and $_{19}K^{40}$ are two isotopes of the element potassium. Note that the two nuclei $_{19}K^{40}$ and $_{20}Ca^{40}$ have the same mass number but different atomic number. Such nuclei are called isobars. Atoms of different elements with the same atomic mass number but different atomic numbers are called isobars. Similarly, the two elements $_{6}C^{14}$ and $_{7}N^{14}$ form another set of isobars.

Isotones

Now consider the two nuclei $_{20}Ca^{40}$ and $_{19}K^{39}$ the atomic mass numbers of calcium and potassium are 40 and 39. Their atomic numbers are 20 and 19. The difference between the atomic mass number and atomic number gives the number of neutrons present in a nucleus. Thus, the number of neutrons in $_{20}Ca^{40}$and $_{19}K^{40}$ is 20 each. Such nuclei are called isotones. Isotones are the atoms of different elements with nuclei having the same number of neutrons, but different number of protons. Another set of isotones is $_{14}Si^{31}$ and $_{15}P^{32}$. Here, the neutron number N = A−Z = 17 for both the nuclei.

RADIOACTIVITY

In the year 1896, French physicist A. H. Becquerel discovered some new radiations emitted spontaneously by crystals of potassium uranyl sulphate, $K_2UO_2(SO_4)_2$. On further investigation, he found that these rays were emitted by the element uranium. It was experimentally found that uranium emitted these radiations irrespective of its state of chemical combination and physical conditions such as temperature, pressure, etc. It showed that the phenomenon involved was related to its nucleus. Some more experimental observations were that these radiations have more penetrating power than X-rays and they get deflected in the presence of an electrical field and a magnetic field. These new radiations were named Becquerel rays. Subsequently, Marie Curie along with her husband Pierre Curie found two more elements – polonium and radium – that emitted similar radiations. The term radioactivity, which refers to the phenomenon of emission of all such radiations, was coined by Marie Curie.

The phenomenon of radioactivity is defined as the spontaneous emission of highly penetrating radiations by some unstable nuclei. Since these emissions are spontaneous, we call the phenomenon natural radioactivity. Elements that give high energy radiations spontaneously are called radioactive elements. Some radioactive elements are uranium, thorium, polonium and radium.

Rutherford's Experiments

Rutherford conducted many experiments to study the nature of the radioactive rays emitted by radioactive substances. He kept some radioactive substance inside a narrow cavity drilled into a thick lead block. The radiations emitted by the radioactive substance emerged through the cavity. A photographic plate was positioned above the cavity and the radiations were made to pass through a strong electrical field. The radiations were allowed to fall on the photographic plate for few seconds. When the photographic plate was developed, three distinct spots A, B and C were observed. Spot A was very dark and appeared on the negative side of the photographic plate. The angle of deflection of these radiations was very small. Rutherford concluded that the radiation responsible for the formation of spot A must consist of positively charged heavy particles. These radiations were named alpha radiations, and the particles were called alpha particles.

Spot C was moderately dark and appeared on the positive side of the photographic plate. The angle of deflection of these radiations was large. Rutherford concluded that the radiations affecting the photographic plate at spot C must be negatively charged lighter particles. These rays were named beta rays and the particles were called beta particles. Rutherford also concluded that Spot B, formed in the middle of the plate, must be due to radiations that are not affected by the presence of the electrical field. He named them gamma radiations. Further studies showed that alpha particles are the nuclei of helium, beta particles are electrons, and gamma rays are high-energy electromagnetic waves.

Properties of Alpha, Beta, and Gamma Radiations

- Alpha particles are doubly ionised helium atoms or simply the nuclei of helium. The mass of an alpha particle is approximately four times that of a proton, and the charge is two times that of a proton. Beta particles are electrons that originate from the nucleus. Their mass and charge are equal to the mass and charge of an electron. Gamma rays are electromagnetic radiations of short wavelength.
- The speed of alpha particles ranges from 10^6 to 10^7 m/s. The speed of beta particles is of the order of 10^8m/s. metres per second. Gamma rays travel at the speed of light.
- Alpha particles very strongly ionise the gas through which they pass. The ionising power of alpha particles is 10,000 times stronger than that of gamma rays. The ionisation power of beta particles is less than that of alpha particles, and more than that of gamma particles. The ionising power of gamma particles is very low compared to that of alpha particles and beta particles.
- The penetrating power of alpha particles is small compared to beta particles and gamma particles. The penetrating power of gamma rays is very high. The penetrating power of beta particles is more than that of alpha particles and less than that of gamma rays.
- In the presence of an electric field, alpha particles are deflected towards the negative electrode and beta particles towards the positive electrode. Gamma rays do not get deflected in the presence of either an electrical or a magnetic field. Both alpha and beta particles deflect in the presence of a magnetic field.

- All these radiations can produce fluorescence when incident on material like zinc sulphide. These radiations are harmful and can cause radiation damage.

RADIOISOTOPES AND THEIR USES

The atoms of the same element with the same atomic number but different mass numbers are called isotopes of the element. For example, carbon has three naturally occurring isotopes, C^{12}, C^{13}, and C^{14}, of which C^{14} is unstable and exhibits radioactivity. Isotopes that exhibit radioactivity are called radioisotopes. These radioactive isotopes continuously emit alpha, beta or gamma particles to attain stability.

All elements with atomic number $Z > 83$ exhibit radioactivity naturally, and are known as naturally occurring radioactive isotopes. Radioactive isotopes of smaller atomic numbers can be produced artificially by artificial transmutation. In this process, a stable nucleus is bombarded with high-energy particles like protons, neutrons or alpha particles. The new nucleus so formed is unstable and exhibits radioactivity. For example, when a high-energy neutron collides with the nucleus of nitrogen, C^{14} is formed, which is unstable and exhibits radioactivity. It emits beta particles and converts back to nitrogen to acquire stability. Radioactive isotopes find many applications in different fields, including medicine, agriculture and industry, and in carbon dating.

Uses of Radioactive Isotopes in Medicine

In medicine, radioactive isotopes are used for diagnosis as well as for therapeutic purposes. In many of these applications, the radioisotope concerned is introduced into the body. When used for diagnosis, the course of the radioisotope through different stages of metabolism is studied. This study often helps in determining the existence of disease, its location and character. For example, the functioning of the thyroid gland can be studied by observing a small dose of radioiodine, I^{131}, given to the patient. A radioisotope of iodine is used in the therapy of hyperthyroidism. Similarly, radio iron is used in the investigation and therapy of diseases related to the bone marrow. Radio calcium is used in the diagnosis and treatment of bone cancer. Radioisotopes of sodium and phosphorous, Na^{24} and P^{32}, are very useful in diseases related to the heart and kidneys. High-energy radiation can destroy human cells. In fact, malignant cells are more sensitive to radiation than normal cells. Radiation from Co^{60} is used in the treatment of cancer to kill cancer cells.

Applications of Radioisotopes in Industry

Radio cobalt is used to detect the internal flaws in a cast material. In some applications, radioisotopes are used to dispel static electricity acquired by some materials.

Applications of Radioisotopes in Agriculture

Radioisotopes find several applications in agriculture, too. Unnecessary mutations of plants can be prevented by irradiation or gamma radiation of seeds. This improves the yield. A fertiliser suitable for a particular soil is chosen after determining the phosphorous content of the soil using radio phosphorous. To study the uptake of phosphorous by plants, the isotope P^{32} is used. To study the transport of minerals in plants, S^{34} is used. Perishable goods like cereals are kept fresh beyond their normal life by exposing them to mild gamma radiation. The gamma radiation destroys bacteria.

Carbon Dating

Another important application of radioisotopes is found in carbon dating, where the radioactive C^{14} isotope is used. Carbon dating is a technique developed to determine the approximate age of ancient biological material. Ordinary C^{12} as well as the radioactive C^{14} combine with oxygen to form carbon dioxide. In photosynthesis, carbon dioxide is absorbed by plants, and they, in turn, are eaten by animals. So a leaf or a tree or even a bone contains both the isotopes of carbon. Because C^{14} is so well mixed up with C^{12}, the ratio of C^{14} to $C^{12}$is the same in a sample of a leaf from a tree, or a part of an animal's body. Radioactive C^{14} atoms constantly change back to N^{14} atoms. In living things, the ratio remains the same because the decayed C^{14} is replaced by the food they take. However, as soon as a plant or animal dies, the C^{14} atoms that decay are no longer replaced, so the amount of C^{14} in that once-living thing decreases as time passes. In other words, the ratio of C^{14} to C^{12} gets smaller. Hence the approximate age of a biological material can be determined.