Course: Physics IV (6444)
Semester: Autumn, 2021

ASSIGNMENT No. 2

Q.1 What are forces of nature? Explain effect of these forces on other phenomenon.

The four fundamental forces act upon us every day, whether we realize it or not. From playing basketball, to launching a rocket into space, to sticking a magnet on your refrigerator - all the forces that all of us experience every day can be whittled down to a critical quartet: Gravity, the weak force, electromagnetism, and the strong force. These forces govern everything that happens in the universe.

Gravity

Gravity is the attraction between two objects that have mass or energy, whether this is seen in dropping a rock from a bridge, a planet orbiting a star or the moon causing ocean tides. Gravity is probably the most intuitive and familiar of the fundamental forces, but it's also been one of the most challenging to explain.

Isaac Newton was the first to propose the idea of gravity, supposedly inspired by an apple falling from a tree. He described gravity as a literal attraction between two objects. Centuries later, Albert Einstein suggested, through his theory of general relativity, that gravity is not an attraction or a force. Instead, it's a consequence of objects bending space-time. A large object works on space-time a bit like how a large ball placed in the middle of a sheet affects that material, deforming it and causing other, smaller objects on the sheet to fall toward the middle.

Though gravity holds planets, stars, solar systems and even galaxies together, it turns out to be the weakest of the fundamental forces, especially at the molecular and atomic scales. Think of it this way: How hard is it to lift a ball off the ground? Or to lift your foot? Or to jump? All of those actions are counteracting the gravity of the entire Earth. And at the molecular and atomic levels, gravity has almost no effect relative to the other fundamental forces.

The weak force

The weak force, also called the weak nuclear interaction, is responsible for particle decay. This is the literal change of one type of subatomic particle into another. So, for example, a neutrino that strays close to a neutron can turn the neutron into a proton while the neutrino becomes an electron.

Physicists describe this interaction through the exchange of force-carrying particles called bosons. Specific kinds of bosons are responsible for the weak force, electromagnetic force and strong force. In the weak force, the bosons are charged particles called W and Z bosons. When subatomic particles such as protons, neutrons and electrons come within 10^-18 meters, or 0.1% of the diameter of a proton, of one another, they can exchange these bosons. As a result, the subatomic particles decay into new particles, according to Georgia State University's HyperPhysics website.

The weak force is critical for the nuclear fusion reactions that power the sun and produce the energy needed for most life forms here on Earth. It's also why archaeologists can use carbon-14 to date ancient bone, wood and other formerly living artifacts. Carbon-14 has six protons and eight neutrons; one of those neutrons decays into a proton to make nitrogen-14, which has seven protons and seven neutrons. This decay happens at a predictable rate, allowing scientists to determine how old such artifacts are.

Electromagnetic force

The electromagnetic force, also called the Lorentz force, acts between charged particles, like negatively charged electrons and positively charged protons. Opposite charges attract one another, while like charges repel. The greater the charge, the greater the force. And much like gravity, this force can be felt from an infinite distance (albeit the force would be very, very small at that distance).

As its name indicates, the electromagnetic force consists of two parts: the electric force and the magnetic force. At first, physicists described these forces as separate from one another, but researchers later realized that the two are components of the same force.

The electric component acts between charged particles whether they're moving or stationary, creating a field by which the charges can influence each other. But once set into motion, those charged particles begin to display the second component, the magnetic force. The particles create a magnetic field around them as they move. So when electrons zoom through a wire to charge your computer or phone or turn on your TV, for example, the wire becomes magnetic.

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Electromagnetic forces are transferred between charged particles through the exchange of massless, force-carrying bosons called photons, which are also the particle components of light. The force-carrying photons that swap between charged particles, however, are a different manifestation of photons. They are virtual and undetectable, even though they are technically the same particles as the real and detectable version, according to the University of Tennessee, Knoxville.

The electromagnetic force is responsible for some of the most commonly experienced phenomena: friction, elasticity, the normal force and the force holding solids together in a given shape. It's even responsible for the drag that birds, planes and even Superman experience while flying. These actions can occur because of charged (or neutralized) particles interacting with one another. The normal force that keeps a book on top of a table (instead of gravity pulling the book through to the ground), for example, is a consequence of electrons in the table's atoms repelling electrons in the book's atoms.

The strong nuclear force

The strong nuclear force, also called the strong nuclear interaction, is the strongest of the four fundamental forces of nature. It's 6 thousand trillion trillion trillion (that's 39 zeroes after 6!) times stronger than the force of gravity, according to the HyperPhysics website. And that's because it binds the fundamental particles of matter together to form larger particles. It holds together the quarks that make up protons and neutrons, and part of the strong force also keeps the protons and neutrons of an atom's nucleus together.

Much like the weak force, the strong force operates only when subatomic particles are extremely close to one another. They have to be somewhere within 10^-15 meters from each other, or roughly within the diameter of a proton.

The strong force is odd, though, because unlike any of the other fundamental forces, it gets weaker as subatomic particles move closer together. It actually reaches maximum strength when the particles are farthest away from each other, according to Fermilab. Once within range, massless charged bosons called gluons transmit the strong force between quarks and keep them "glued" together. A tiny fraction of the strong force called the residual strong force acts between protons and neutrons. Protons in the nucleus repel one another because of their similar charge, but the residual strong force can overcome this repulsion, so the particles stay bound in an atom's nucleus.

Q.2 Derive the equation of continuity and give its physical interpretation in your own words.

The continuity equation is defined as the product of cross-sectional area of the pipe and the velocity of the fluid at any given point along the pipe is constant.

Continuity equation represents that the product of cross-sectional area of the pipe and the fluid speed at any point along the pipe is always constant. This product is equal to the volume flow per second or simply the flow rate. The continuity equation is given as:

R = A v = constant

Where,

- R is the volume flow rate
- A is the flow area
- v is the flow velocity

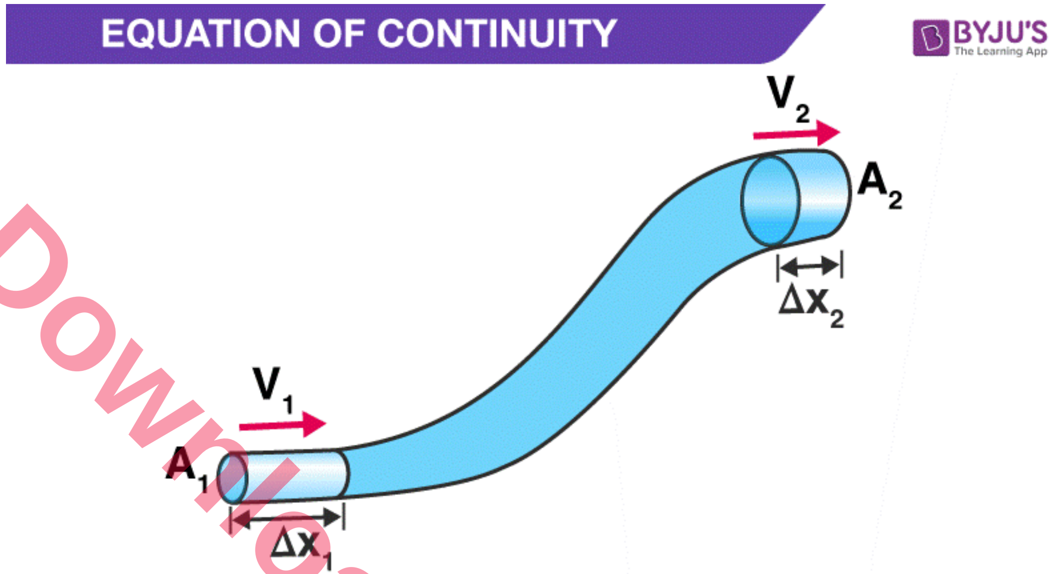
Assumption of Continuity Equation

Following are the assumptions of continuity equation:

- The tube is having a single entry and single exit
- The fluid flowing in the tube is non-viscous
- The flow is incompressible
- The fluid flow is steady

Derivation

Consider the following diagram:



Now, consider the fluid flows for a short interval of time in the tube. So, assume that short interval of time as **Δt**. In this time, the fluid will cover a distance of Δx_1 with a velocity v_1 at the lower end of the pipe.

At this time, the distance covered by the fluid will be:

$\Delta x_1 = v_1 \Delta t$

Now, at the lower end of the pipe, the volume of the fluid that will flow into the pipe will be:

$V = A_1 \Delta x_1 = A_1 v_1 \Delta t$

It is known that **mass (m) = Density (ρ) × Volume (V).** So, the mass of the fluid in Δx_1 region will be:

Δm₁= Density × Volume

=> $\Delta m_1 = \rho_1 A_1 v_1 \Delta t$ ———**(Equation 1)**

Now, the mass flux has to be calculated at the lower end. Mass flux is simply defined as the mass of the fluid per unit time passing through any cross-sectional area. For the lower end with cross-sectional area A_1, mass flux will be:

$\Delta m_{1/\Delta t} = \rho_1 A_1 v_1$ ———**(Equation 2)**

Similarly, the mass flux at the upper end will be:

$\Delta m_{2/\Delta t} = \rho_2 A_2 v_2$ ———**(Equation 3)**

Here, v_2 is the velocity of the fluid through the upper end of the pipe i.e. through Δx_2, in **Δt** time and A_2, is the cross-sectional area of the upper end.

In this, the density of the fluid between the lower end of the pipe and the upper end of the pipe remains the same with time as the flow is steady. So, the mass flux at the lower end of the pipe is equal to the mass flux at the upper end of the pipe i.e. **Equation 2 = Equation 3.**

Thus,

$\rho_1 A_1 v_1 = \rho_2 A_2 v_2$ ———**(Equation 4)**

This can be written in a more general form as:

$\rho A v = \text{constant}$

The equation proves the law of conservation of mass in fluid dynamics. Also, if the fluid is incompressible, the density will remain constant for steady flow. So, $\rho_1 = \rho_2$.

Thus, **Equation 4** can be now written as:

$A_1 v_1 = A_2 v_2$

This equation can be written in general form as:

A v = constant

Now, if **R** is the volume flow rate, the above equation can be expressed as:

R = A v = constant

This was the derivation of continuity equation.

Continuity Equation in Cylindrical Coordinates

Following is the continuity equation in cylindrical coordinates:

$\partial\rho / \partial t+1 / r\ \partial r\rho u / \partial r+1 / r\ \partial\rho v / \partial\theta+\partial\rho w / \partial z=$

Incompressible Flow Continuity Equation

Following is the continuity equation for incompressible flow as the density, ρ = constant and is independent of space and time, we get:

$\nabla.v = 0$

Steady Flow Continuity Equation

Following is the continuity equation in cylindrical coordinates:

$\partial / \partial x(\rho u)+\partial / \partial y(\rho v)+\partial / \partial z(\rho w)=0$

Q.3 State and explain Liquid Drop Model by providing examples.

In nuclear physics, the **semi-empirical mass formula** (SEMF) (sometimes also called the **Weizsäcker formula**, **Bethe–Weizsäcker formula**, or **Bethe–Weizsäcker mass formula** to distinguish it from the Bethe–Weizsäcker process) is used to approximate the mass and various other properties of an atomic nucleus from its number of protons and neutrons. As the name suggests, it is based partly on theory and partly on empirical measurements. The formula represents the **liquid drop model** proposed by George Gamow,[1] which can account for most of the terms in the formula and gives rough estimates for the values of the coefficients. It was first formulated in 1935 by German physicist Carl Friedrich von Weizsäcker and although refinements have been made to the coefficients over the years, the structure of the formula remains the same today. The formula gives a good approximation for atomic masses and thereby other effects. However, it fails to explain the existence of lines of greater binding energy at certain numbers of protons and neutrons. These numbers, known as magic numbers, are the foundation of the nuclear shell model.

Scattering experiments suggest that nuclei have approximately constant density, so that the nuclear radius can be calculated by using that density as if the nucleus were a drop of a uniform liquid. A liquid drop model of the nucleus would take into account the fact that the forces on the nucleons on the surface are different from those on nucleons on the interior where they are completely surrounded by other attracting nucleons. This is something similar to taking account of surface tension as a contributor to the energy of a tiny liquid drop. The volume of the liquid drop is proportional to the mass number A, and the surface would then be proportional to the two-thirds power of A.

The first step toward a liquid drop model of the nucleus would then be to postulate a volume term and a surface term in the form:

$$E_b \approx \underbrace{C_1 A}_{\text{Volume term}} \quad \underbrace{- C_2 A^{2/3}}_{\text{Surface term}}$$

This simple model in fact gives a reasonable approximation of the variation of nuclear binding energy with mass number when the constants have the values

$$C_1 = 15.75 MeV, \quad C_2 = 17.8 MeV$$

Another contribution to the binding energy would be the coulomb repulsion of the protons, so there should be a negative term proportional to the square of the atomic number Z :

$$\Delta E_b^{Coulomb} \approx \frac{-(0.711 MeV) Z^2}{A^{1/3}}$$

The Pauli principle favors nuclei in which A=2Z, so the empirical model of binding energy contains a term of the form

$$\Delta E_b^{Pauli} \approx \frac{-(23.7 MeV)(A-2Z)^2}{A}$$

The Pauli principle also favors nuclear configurations with even numbers of neutrons and protons. In the liquid drop model, this is included by using the even-odd nucleus as a reference and adding a correction term which is positive for even-even nuclei and negative for odd-odd nuclei. This strategy for modeling the nuclear binding energy is attributed to Weizsaecker and called the Weizsaecker formula.

Q.4 What is basic concept of plasma, explain in detail. Also describe how plasma can be produced?

In the mid nineteenth century the Czech physiologist Jan Evangelista Purkinje introduced use of the Greek word plasma (meaning “formed” or “molded”) to denote the clear fluid that remains after removal of all the corpuscular material in blood. About half a century later, the American scientist Irving Langmuir proposed in 1922 that the electrons, ions, and neutrals in an ionized gas could similarly be considered as corpuscular material entrained in some kind of fluid medium and called this entraining medium plasma. However it turned out that, unlike blood where there really is a fluid medium carrying the corpuscular material, there actually is no "fluid medium" entraining the electrons, ions, and neutrals in an ionized gas. Ever since, plasma scientists have had to explain to friends and acquaintances that they were not studying blood!

Plasma is superheated matter – so hot that the electrons are ripped away from the atoms forming an ionized gas. It comprises over 99% of the visible universe. In the night sky, plasma glows in the form of stars, nebulas, and even the auroras that sometimes ripple above the north and south poles. That branch of lightning that cracks the sky is plasma, so are the neon signs along our city streets. And so is our sun, the star that makes life on earth possible.

Plasma is often called "the fourth state of matter," along with solid, liquid and gas. Just as a liquid will boil, changing into a gas when energy is added, heating a gas will form a plasma – a soup of positively charged particles (ions) and negatively charged particles (electrons).

Because so much of the universe is made of plasma, its behavior and properties are of intense interest to scientists in many disciplines. Importantly, at the temperatures required for the goal of practical fusion energy, all matter is in the form of plasma. Researchers have used the properties of plasma as a charged gas to confine it with magnetic fields and to heat it to temperatures hotter than the core of the sun. Other researchers pursue plasmas for making computer chips, rocket propulsion, cleaning the environment, destroying biological hazards, healing wounds and other exciting applications.

In the 1920s and 1930s a few isolated researchers, each motivated by a specific practical problem, began the study of what is now called plasma physics. This work was mainly directed towards understanding (i) the effect of ionospheric plasma on long-distance short-wave radio propagation and (ii) gaseous electron tubes used for rectification, switching, and voltage regulation in the pre-semiconductor era of electronics. In the 1940s Hannes Alfvén developed a theory of hydromagnetic waves (now called Alfvén waves) and proposed that these waves would be important in astrophysical plasmas.

A typical gas, such as nitrogen or hydrogen sulfide, is made of molecules that have a net charge of zero, giving the gas volume as a whole a net charge of zero. Plasmas, being made of charged particles, may have a net charge of zero over their whole volume but not at the level of individual particles. That means the electrostatic forces between the particles in the plasma become significant, as well as the effect of magnetic fields.

Being made of charged particles, plasmas can do things gases cannot, like conduct electricity. And since moving charges make magnetic fields, plasmas also can have them.

In an ordinary gas, all the particles will behave roughly the same way. So if you have gas in a container and let it cool to room temperature, all the molecules inside will, on average, be moving at the same speed, and if you were to measure the speed of lots of individual particles you'd get a distribution curve with lots of them moving near the average and only a few either especially slowly or quickly. That's because in a gas the molecules, like billiard balls, hit each other and transfer energy between them.

That doesn't happen in a plasma, especially in an electric or magnetic field. A magnetic field can create a population of very fast particles, for example. Most plasmas aren't dense enough for particles to collide with one another very often, so the magnetic and electrostatic interactions become more important.

Speaking of electrostatic interactions, because particles in a plasma – the electrons and ions – can interact via electricity and magnetism, they can do so at far greater distances than an ordinary gas. That in turn means waves become more important when discussing what goes on in a plasma. One such wave is called an Alfvén wave, named for Swedish physicist and Nobel laureate Hannes Alfvén. An Alfvén wave happens when the magnetic field in a plasma is disturbed, creating a wave that travels along the field lines. There's no real analogue to this in ordinary gases. It's possible that Alfvén waves are the reason the temperature of the solar corona– also a plasma – is millions of degrees, while on the surface, it is only thousands.

Another characteristic of plasmas is that they can be held in place by magnetic fields. Most fusion power research is focused on doing just that. To create the conditions for fusion, one needs very hot plasma — at millions of degrees. Since no material can contain it, scientists and engineers have turned to magnetic fields to do the job.

Q.5 What are the different designs of LASER? Also explain types of LASER.

Helium-Neon laser is a type of gas laser in which a mixture of helium and neon gas is used as a gain medium. Helium-Neon laser is also known as He-Ne laser.

A gas laser is a type of laser in which a mixture of gas is used as the active medium or laser medium. Gas lasers are the most widely used lasers.

Gas lasers range from the low power helium-neon lasers to the very high power carbon dioxide lasers. The helium-neon lasers are most commonly used in college laboratories whereas the carbon dioxide lasers are used in industrial applications.

The main advantage of gas lasers (eg: He-Ne lasers) over solid state lasers is that they are less prone to damage by overheating so they can be run continuously.

At room temperature, a ruby laser will only emit short bursts of laser light, each laser pulse occurring after a flash of the pumping light. It would be better to have a laser that emits light continuously. Such a laser is called a continuous wave (CW) laser.

The helium-neon laser was the first continuous wave (CW) laser ever constructed. It was built in 1961 by Ali Javan, Bennett, and Herriott at Bell Telephone Laboratories.

Helium-neon lasers are the most widely used gas lasers. These lasers have many industrial and scientific uses and are often used in laboratory demonstrations of optics.

In He-Ne lasers, the optical pumping method is not used instead an electrical pumping method is used. The excitation of electrons in the He-Ne gas active medium is achieved by passing an electric current through the gas.

The helium-neon laser operates at a wavelength of 632.8 nanometers (nm), in the red portion of the visible spectrum.

Helium-neon laser construction

The helium-neon laser consists of three essential components:

- Pump source (high voltage power supply)
- Gain medium (laser glass tube or discharge glass tube)
- Resonating cavity

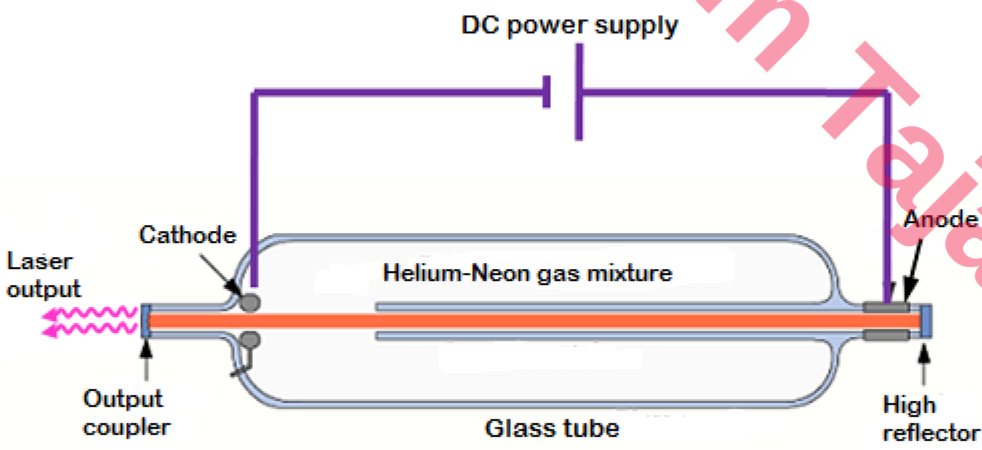
High voltage power supply or pump source

In order to produce the laser beam, it is essential to achieve population inversion. Population inversion is the process of achieving more electrons in the higher energy state as compared to the lower energy state.

In general, the lower energy state has more electrons than the higher energy state. However, after achieving population inversion, more electrons will remain in the higher energy state than the lower energy state.

In order to achieve population inversion, we need to supply energy to the gain medium or active medium. Different types of energy sources are used to supply energy to the gain medium.

In ruby lasers and Nd:YAG lasers, the light energy sources such as flashtubes or laser diodes are used as the pump source. However, in helium-neon lasers, light energy is not used as the pump source. In helium-neon lasers, a high voltage DC power supply is used as the pump source. A high voltage DC supplies electric current through the gas mixture of helium and neon.



Gain medium (discharge glass tube or glass envelope)

The gain medium of a helium-neon laser is made up of the mixture of helium and neon gas contained in a glass tube at low pressure. The partial pressure of helium is 1 mbar whereas that of neon is 0.1 mbar.

The gas mixture is mostly comprised of helium gas. Therefore, in order to achieve population inversion, we need to excite primarily the lower energy state electrons of the helium atoms.

In He-Ne laser, neon atoms are the active centers and have energy levels suitable for laser transitions while helium atoms help in exciting neon atoms.

Electrodes (anode and cathode) are provided in the glass tube to send the electric current through the gas mixture. These electrodes are connected to a DC power supply.

Resonating cavity

The glass tube (containing a mixture of helium and neon gas) is placed between two parallel mirrors. These two mirrors are silvered or optically coated.

Each mirror is silvered differently. The left side mirror is partially silvered and is known as output coupler whereas the right side mirror is fully silvered and is known as the high reflector or fully reflecting mirror.

The fully silvered mirror will completely reflect the light whereas the partially silvered mirror will reflect most part of the light but allows some part of the light to produce the laser beam.

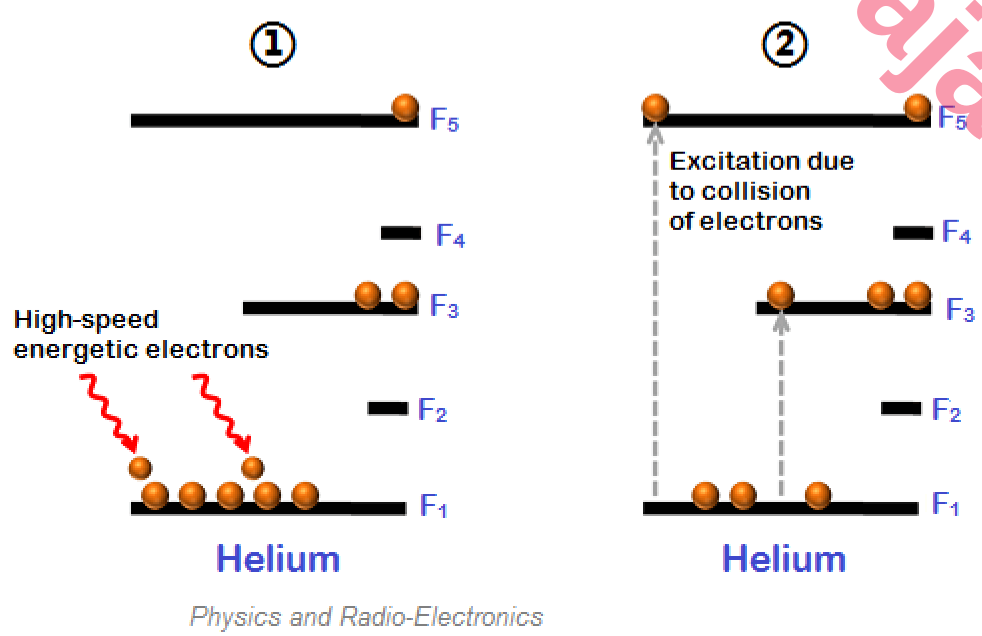
Working of helium-neon laser

In order to achieve population inversion, we need to supply energy to the gain medium. In helium-neon lasers, we use high voltage DC as the pump source. A high voltage DC produces energetic electrons that travel through the gas mixture.

The gas mixture in helium-neon laser is mostly comprised of helium atoms. Therefore, helium atoms observe most of the energy supplied by the high voltage DC.

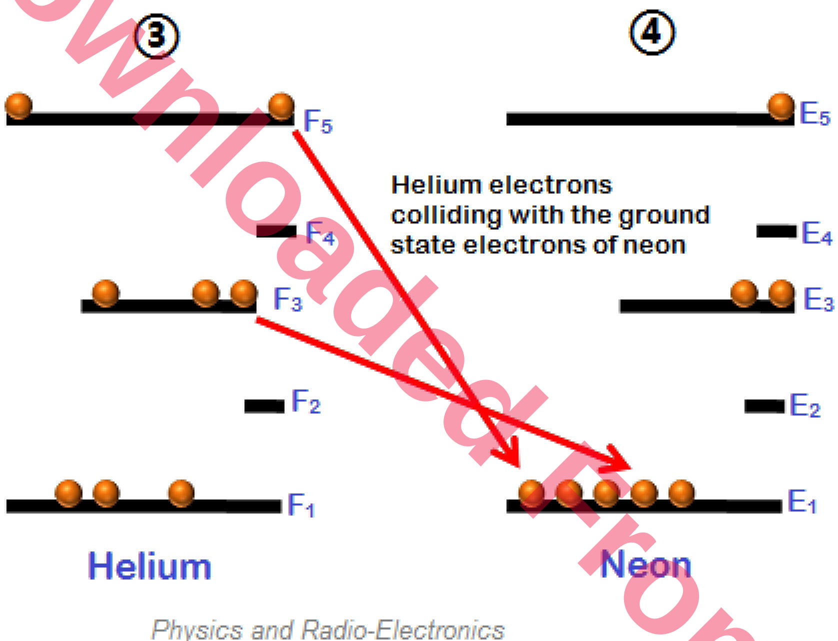
When the power is switched on, a high voltage of about 10 kV is applied across the gas mixture. This power is enough to excite the electrons in the gas mixture. The electrons produced in the process of discharge are accelerated between the electrodes (cathode and anode) through the gas mixture.

In the process of flowing through the gas, the energetic electrons transfer some of their energy to the helium atoms in the gas. As a result, the lower energy state electrons of the helium atoms gain enough energy and jumps into the excited states or metastable states. Let us assume that these metastable states are F_3 and F_5.

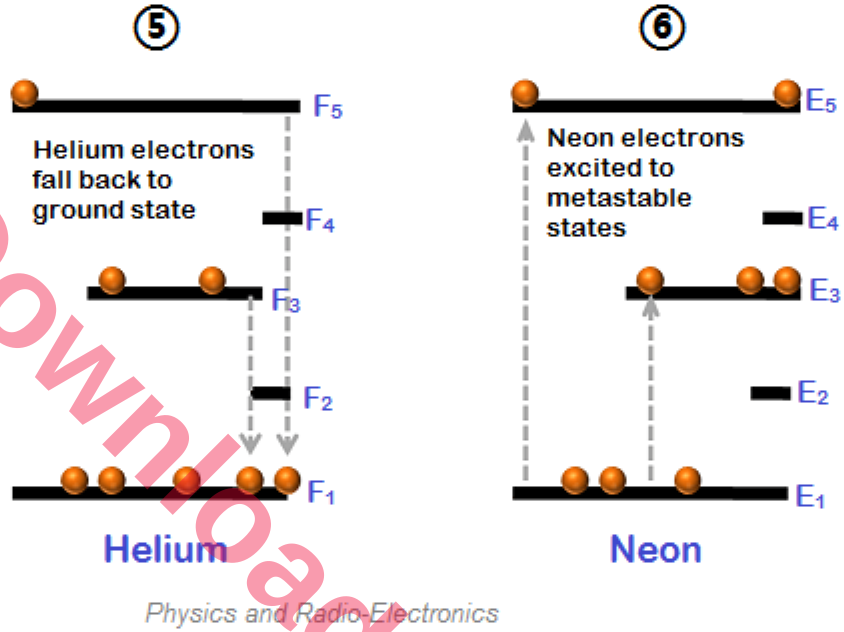


The metastable state electrons of the helium atoms cannot return to ground state by spontaneous emission. However, they can return to ground state by transferring their energy to the lower energy state electrons of the neon atoms.

The energy levels of some of the excited states of the neon atoms are identical to the energy levels of metastable states of the helium atoms. Let us assume that these identical energy states are $F_3 = E_3$ and $F_5 = E_5$. E_3 and E_5 are excited states or metastable states of neon atoms.



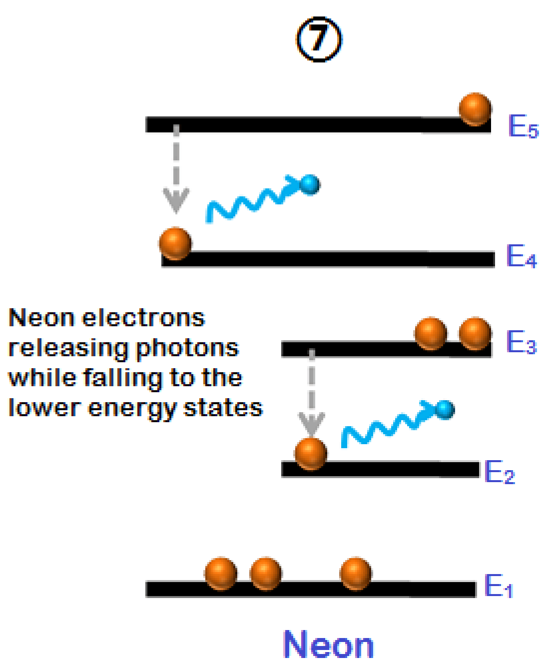
Unlike the solid, a gas can move or flow between the electrodes. Hence, when the excited electrons of the helium atoms collide with the lower energy state electrons of the neon atoms, they transfer their energy to the neon atoms. As a result, the lower energy state electrons of the neon atoms gain enough energy from the helium atoms and jumps into the higher energy states or metastable states (E_3 and E_5) whereas the excited electrons of the helium atoms will fall into the ground state. Thus, helium atoms help neon atoms in achieving population inversion.



Likewise, millions of ground state electrons of neon atoms are excited to the metastable states. The metastable states have the longer lifetime. Therefore, a large number of electrons will remain in the metastable states and hence population inversion is achieved.

After some period, the metastable states electrons (E_3 and E_5) of the neon atoms will spontaneously fall into the next lower energy states (E_2 and E_4) by releasing photons or red light. This is called spontaneous emission.

The neon excited electrons continue on to the ground state through radiative and nonradiative transitions. It is important for the continuous wave (CW) operation.



The light or photons emitted from the neon atoms will moves back and forth between two mirrors until it stimulates other excited electrons of the neon atoms and causes them to emit light. Thus, optical gain is achieved. This process of photon emission is called stimulated emission of radiation.

The light or photons emitted due to stimulated emission will escape through the partially reflecting mirror or output coupler to produce laser light.

Advantages of helium-neon laser

- Helium-neon laser emits laser light in the visible portion of the spectrum.
- High stability
- Low cost
- Operates without damage at higher temperatures

Disadvantages of helium-neon laser

- Low efficiency
- Low gain
- Helium-neon lasers are limited to low power tasks

Applications of helium-neon lasers

- Helium-neon lasers are used in industries.
- Helium-neon lasers are used in scientific instruments.
- Helium-neon lasers are used in the college laboratories.