

# What is plasma?

- Plasma can be considered as an ionized gas.
- Also called “fourth state of matter”.
- How to generate plasma?

Heating

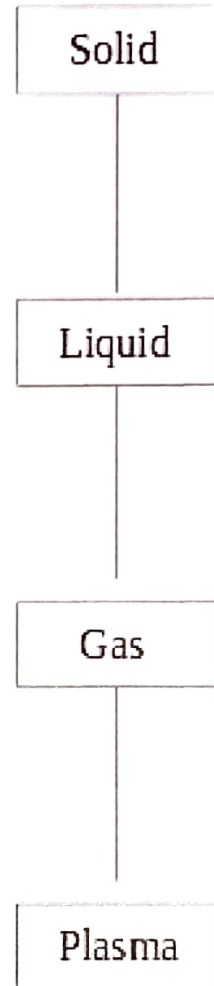


Solid

Liquid

Gas

Plasma



## Formal Definition of Plasma

***“Plasma is a collection of charged and neutral particles which exhibit the collective behaviour and obey the condition of quasi-neutrality.”***

Collective Behaviour

Charged particles can communicate to the other charged particles situated at large distance through long-range EM forces. Due to this connectivity, the plasma responds collectively to any perturbation.

Quasi neutrality

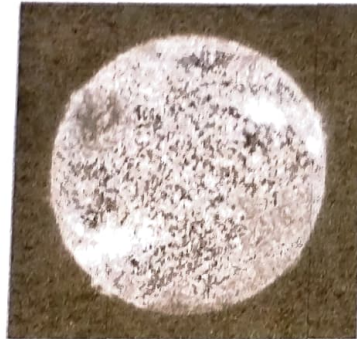
Number density of electrons ( $n_e$ ) is approximately equal to number density of ions ( $n_i$ ).

# Examples of Plasma Systems

It is believed that around 99% visible matter in the universe is in plasma state



**LIGHTNING**



**SUN**



**NEBULA**



**AURORAS**

## Plasma Temperature

Concept of temperature: A gas in thermal equilibrium, the most probable distribution of velocities of the particles is given by the Maxwellian distribution:  $f(v) = A \exp(-mv^2/2kT)$

where  $A = n(m/2\pi kT)^{1/2}$  with  $n$  representing the number density. Then the averaged kinetic energy of particles is calculated as:

$$E_{av} = \left( \int_{-\infty}^{\infty} (mv^2/2) f(v) dv \right) / \int_{-\infty}^{\infty} f(v) dv$$
$$= 1/2 kT$$

Averaged kinetic energy is  $1/2kT$  for 1D and  $3/2kT$  for 3D.

Therefore, temperature is nothing but the averaged kinetic energy of the particles in equilibrium.

## Plasma Temperature (Contd.)

- Collisions of the particles which thermalize the system and take the system to equilibrium state in which particles follow the Maxwellian distribution and the temperature can be defined in terms of averaged kinetic energy of the particles.
- Different types of collisions are possible in plasma as there can be three different types of species: electrons, ions, and neutral.
- Each species can be in its own thermal equilibrium and there can be different temperatures in plasma; electron temperature  $T_e$ , ion temperature  $T_i$ , neutral temperature  $T_n$ .
- If we wait for a long enough time, the inter-species collisions equilibrate different temperatures i.e.,  $T_e = T_i = T_n = T$ .