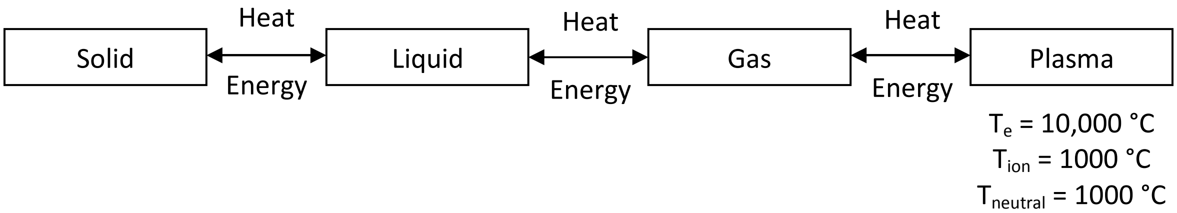
What are Plasmas?

Definition 1: Plasma = the 4^{th} state of matter.



Since 1 eV is about 11,600 K, then T_e is about 1 eV or 1.602E-19 J.

Definition 2: Plasma = ionized gas.

There are 2 parts in this definition:

1. **Gaseous state** – average separation between particles is much greater than the atomic scale. If n = charge particle density, and a_0 = atomic scale (Å = 10^{-8} cm), then

$$\boxed{n^{-1/3} >> a_0}$$

so that each particle occupied on average a volume of 1/n cm^3. For interstellar medium, n ≈ 1 cm^{-3}; for fusion plasma, n ≈ 10^{19} cm^{-3}.

2. **Ionization** – Plasma temperature is much greater than ionization temperature (E_i),

$$\boxed{k_B T > E_i},$$

where k_B = Boltzmann constant = 1.3807E-23 J/K = 8.6174E-5 eV/K, and T = plasma temperature. Since $E_i \approx e^2/(4\pi\varepsilon_0)a_0$,

$$n^{-1/3} >> \frac{e^2}{4\pi\varepsilon_0 E_i} >> \frac{e^2}{4\pi\varepsilon_0 k_B T}.$$

ε_0 is the permittivity of free space and is = 8.8542E-12 F/m. This is material ability to polarize and permit electric field.

99% of matter in the universe is in plasma state. However, we are living in the 1% where plasma does not commonly exist. This is because under the earth atmosphere, the amount of ionization is very low.

However, this doesn't mean that plasmas cannot exist in nature on earth. There are couple examples:

1. **Lightning** – happen when atmosphere discharge electricity. Inside lightning can be as hot as 30,000 °C.

2. **Ionosphere** – is the outer later of the earth where gas has been ionized by solar radiation

3. **Polar light** – is caused by collision between charged particles and atoms in the upper atmosphere. These charged particles are from outer space, usually in the form of solar wind.

There are many applications of plasmas:

1. **Lightning source** – neon sign, lightning bulb, fluorescent lamp.

2. **Fusion energy** – need to make particle with high energy that cannot be done or very inefficient by direct heating method.

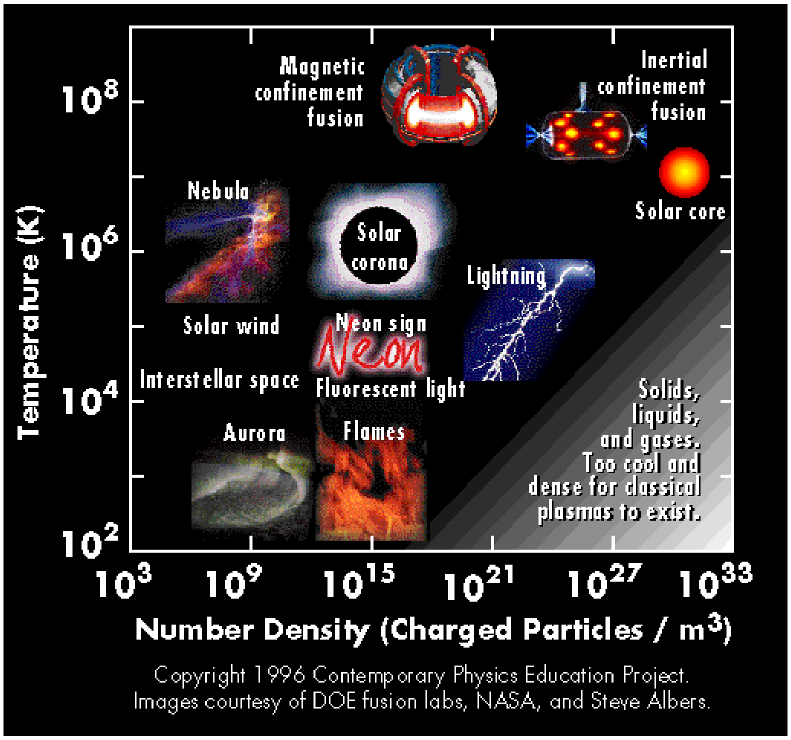
3. **Plasma processing** – plasma has been used to create integrate circuit.

Edged with plasma | Edged with chemical

4. **Ion propulsion** – shoot plasma out of rocket to propel interplanetary spacecraft.

5. **Gas laser** – use gas discharge to exit atom which would then give rise to light amplification.

6. **Plasma TV** – ionized xenon and neon gases inside collide with electrode and emit photon, which then excites phosphor to give off colored light.



What does plasma temperature really mean physically?

In thermal equilibrium, which is state where plasma and gas like to be in, particles have all velocities. The velocity distribution of the particles is called Maxwellian distribution. In one dimension, we can write the distribution function as

$$f(u) = A\exp\left(-\frac{1}{2}mu^2 \Big/ KT\right)$$

where we can calculate the total density from

$$n = \int_{-\infty}^{\infty} f(u)du \,.$$

See homework for how to derive A.

We can calculate the average energy of each particle by

$$E_{av} = \frac{\int_{-\infty}^{\infty} \frac{1}{2}mu^2 f(u)du}{\int_{-\infty}^{\infty} f(u)du} \,.$$

Define thermal velocity $v_{th} = (2KT/m)^{1/2}$ so that $f(u) = A\exp\left(-u^2 / v_{th}^2\right)$, then

$$\int_{-\infty}^{\infty} \frac{1}{2} m u^2 f(u) du = \frac{1}{2} m A \int_{-\infty}^{\infty} u^2 \exp\left(-u^2 / v_{th}^2\right) du$$

$$= \frac{1}{2} m A \left[-\frac{1}{2} v_{th}^2 u \exp\left(-u^2 / v_{th}^2\right)\Big|_{-\infty}^{\infty} + \int_{-\infty}^{\infty} \frac{1}{2} v_{th}^2 \exp\left(-u^2 / v_{th}^2\right) du \right]$$

$$= \frac{1}{2} m A \left[\int_{-\infty}^{\infty} \frac{1}{2} v_{th}^2 \exp\left(-u^2 / v_{th}^2\right) du \right]$$

$$= \frac{1}{4} m v_{th}^2 \left[\int_{-\infty}^{\infty} A \exp\left(-u^2 / v_{th}^2\right) du \right] = \frac{1}{4} m v_{th}^2 \left[\int_{-\infty}^{\infty} f(u) du \right]$$

Thus, $E_{av} = \frac{1}{4} m v_{th}^2 = \frac{1}{2} KT$

For three-dimension, we find that $E_{av} = \frac{3}{2} KT$.

So for each degree of freedom, $\boxed{E_{av} = \frac{1}{2} KT}$