BASIC PLASMAS PROPERTIES

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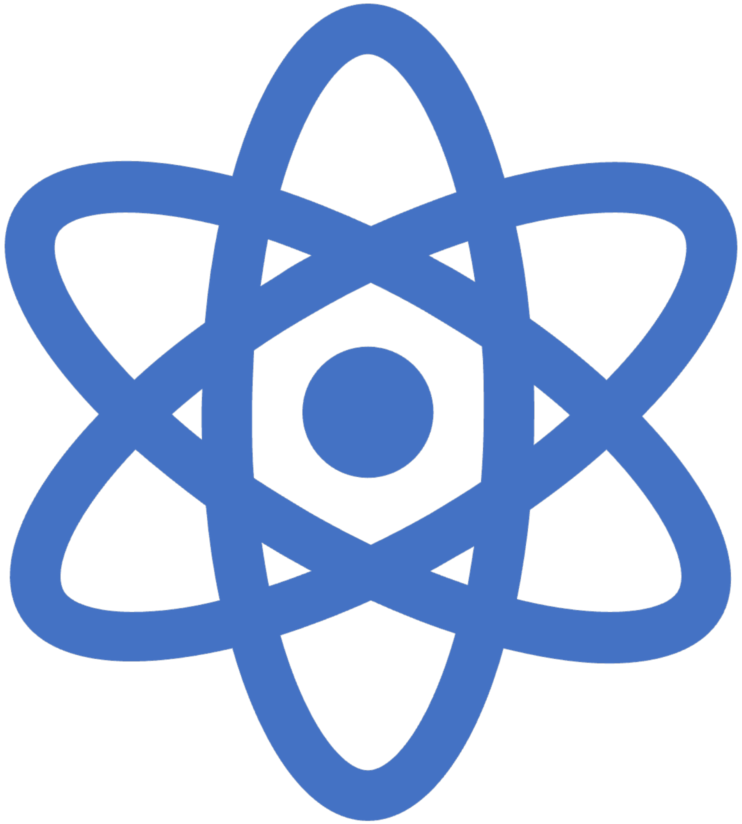
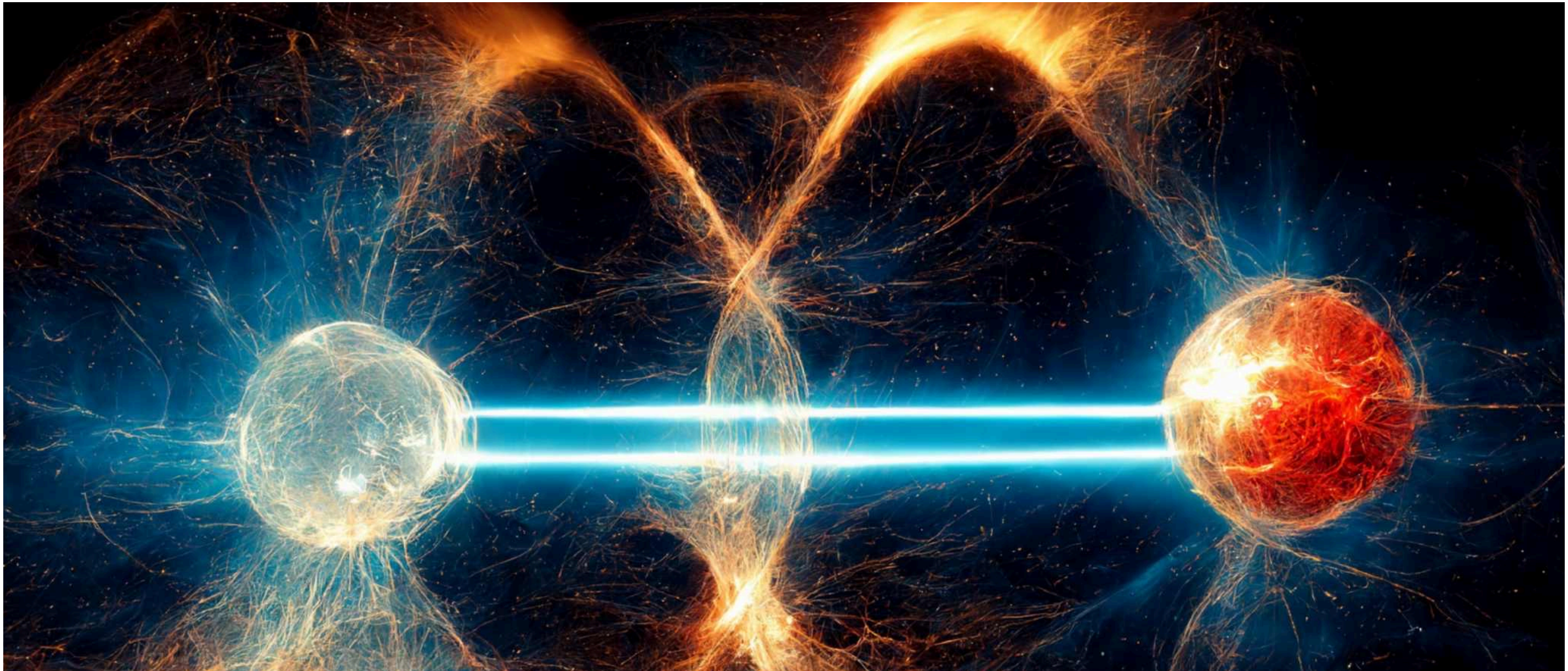
Proseminar "Plasma Physics"

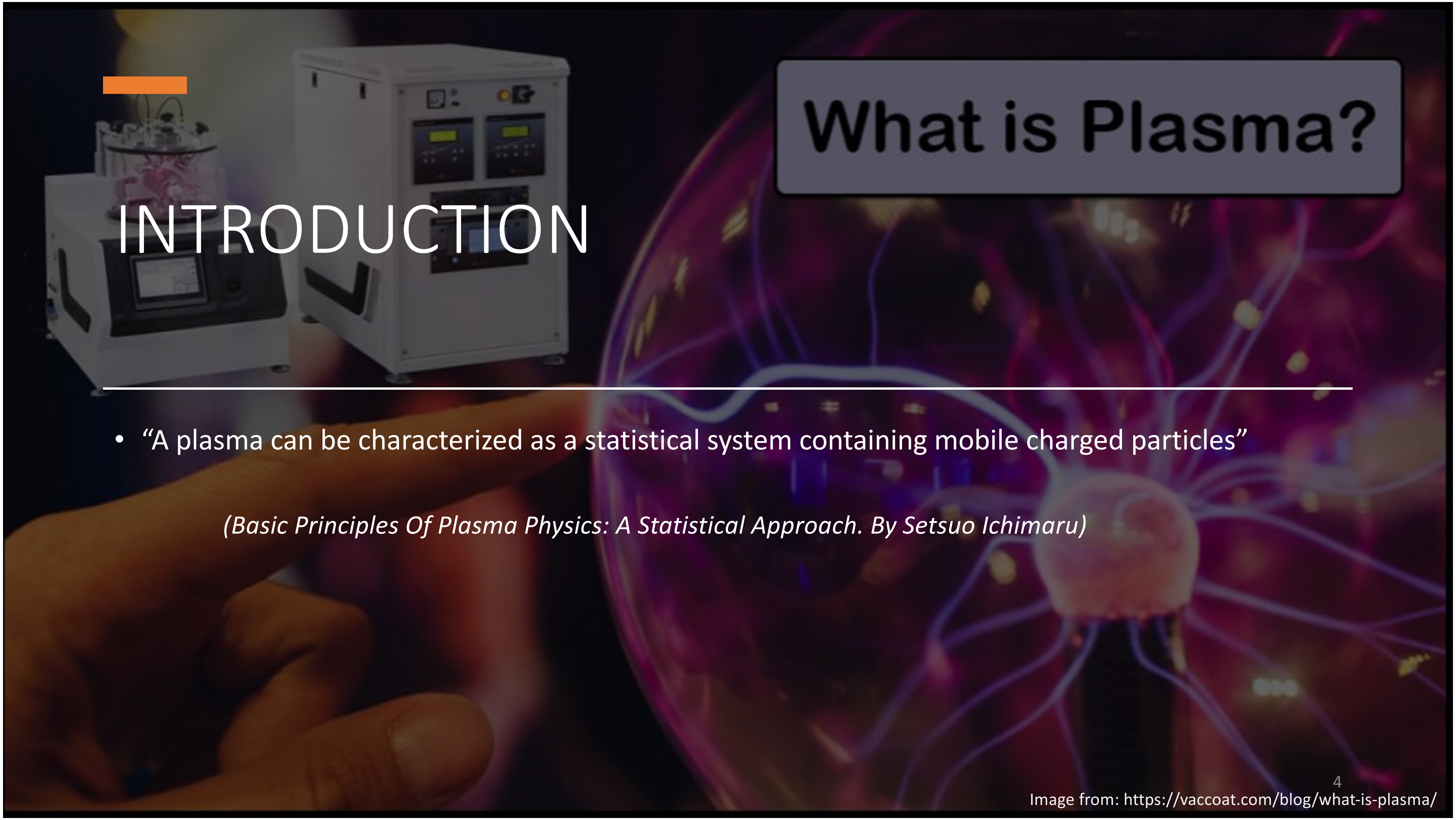
OUTLINE

- MOTIVATION
- INTRODUCTION
- DIFFERENCES BETWEEN PLASMA AND SOLID OR LIQUIDS
- MOST TYPICAL PLASMA FORMS
- PLASMA PROPERTIES
- IONOSPHERE
- CLASSIFICATION OF PLASMAS
- PLASMA APPLICATIONS





MOTIVATION



INTRODUCTION

- "A plasma can be characterized as a statistical system containing mobile charged particles"

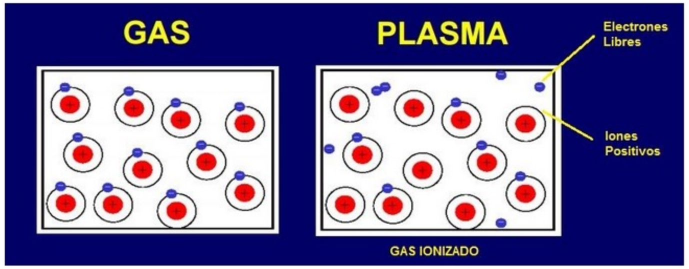
(Basic Principles Of Plasma Physics: A Statistical Approach. By Setsuo Ichimaru)

Image from: https://vaccoat.com/blog/what-is-plasma/

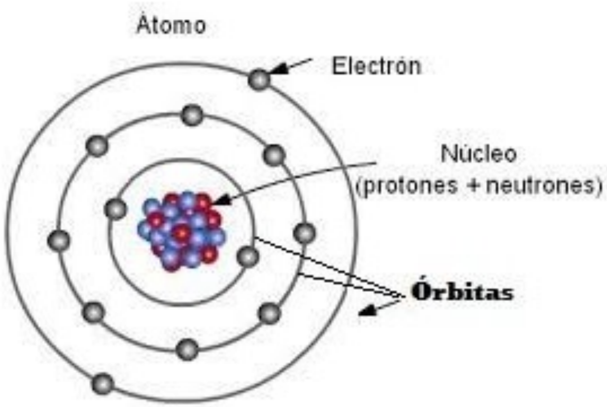
INTRODUCTION

"From Neutrality to Ionization: Exploring the Transition to Plasma State in Matter“

Defining plasma as an ionized gas where energy liberates electrons from atomic bonds, creating a dynamic interplay between ions and electrons.



(https://www.areaciencias.com/fisica/plasma/)



(https://www.areaciencias.com/fisica/plasma/)

DIFFERENCES BETWEEN PLASMA AND SOLID OR LIQUIDS

- Plasma is a unique state of matter with charged particles, different from solids, liquids, and gases. It features free electrons and positive ions due to ionization, displaying special properties like conductivity.

MOST TYPICAL PLASMA FORMS

Artificially created Plasma

- Plasma screen (television)
- The substance inside fluorescent and neon lamps
- Plasma rocket engines
- Corona Discharge Ozone Generator
- Controlled termonuclear fusion
- Electric arc in arc lamp in arc welding
- Impact on the substance by laser radiation
- A glowing sphere from a nuclear explosion

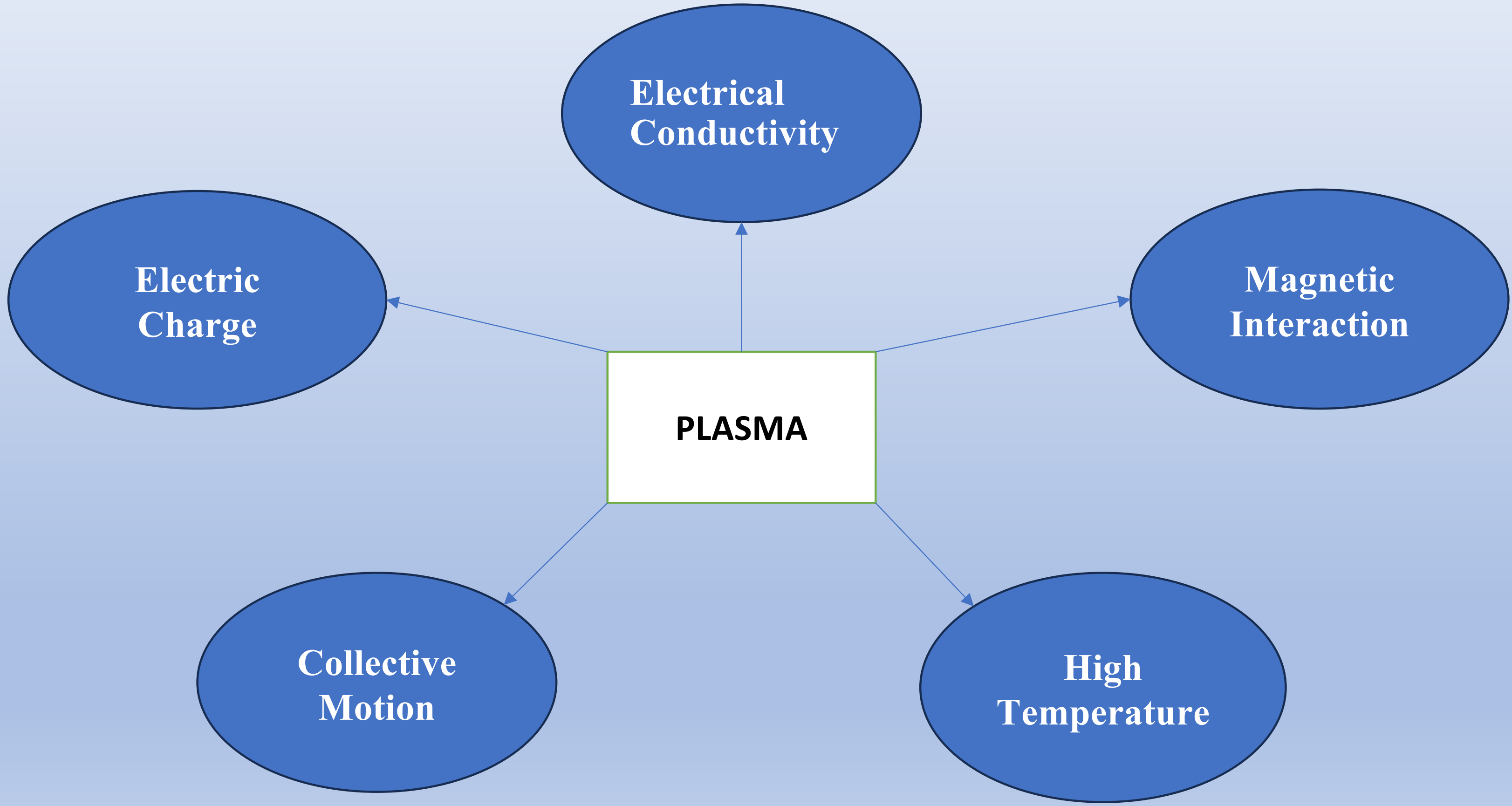
Natural Plasma of the Earth

- Ray
- Elmo´s fire
- Ionosphere
- A flame (low temperature plasma)

Space and astrophysical Plasma

- The sun and other stars (those that exist due to termonuclear reactions)
- The solar wind
- Space (space between planets, stars and galaxies)
- Interstellar nebula

PLASMA PROPERTIES.
BASIC PROPERTIES



DEBYE SHIELDING

$$n_s = n_0 \exp(-e_s \Phi/T), \quad (1.11)$$

where $\Phi(\mathbf{r})$ is the electrostatic potential, and n_0 and T are constant. From $e_i = -e_e = e$, it is clear that quasi-neutrality requires the equilibrium potential to be zero. Suppose that the equilibrium potential is perturbed, by an amount $\delta\Phi(\mathbf{r})$, as a consequence of a small, localized, perturbing charge density, $\delta\rho_{\rm ext}$. The total perturbed charge density is written

$$\delta\rho = \delta\rho_{\rm ext} + e(\delta n_i - \delta n_e) \simeq \delta\rho_{\rm ext} - 2e^2 n_0 \delta\Phi/T. \quad (1.12)$$

Thus, Poisson's equation yields

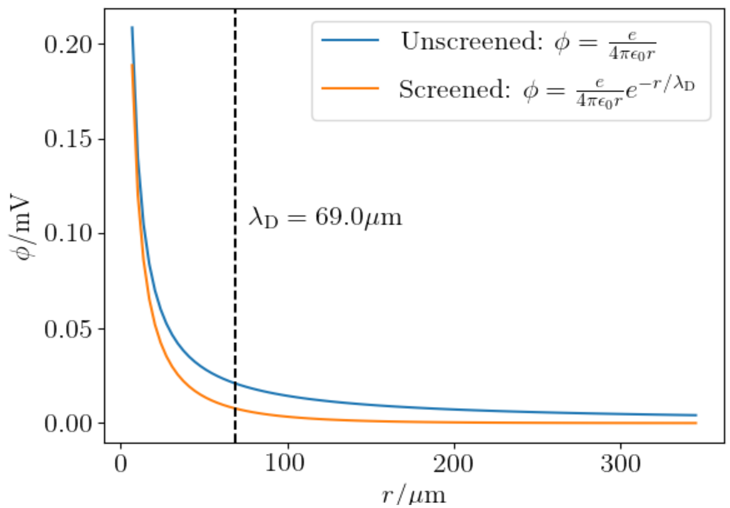
$$\nabla^2 \delta\Phi = -\frac{\delta\rho}{\epsilon_0} = -\left(\frac{\delta\rho_{\rm ext} - 2e^2 n_0 \delta\Phi/T}{\epsilon_0}\right), \quad (1.13)$$

which reduces to

$$\left(\nabla^2 - \frac{2}{\lambda_D^2}\right)\delta\Phi = -\frac{\delta\rho_{\rm ext}}{\epsilon_0}. \quad (1.14)$$

If the perturbing charge density actually consists of a point charge q, located at the origin, so that $\delta\rho_{\rm ext} = q\,\delta(\mathbf{r})$, then the solution to the previous equation is written

$$\delta\Phi(r) = \frac{q}{4\pi\epsilon_0 r}\exp\left(-\frac{\sqrt{2}\,r}{\lambda_D}\right). \quad (1.15)$$



(Plasma Physics An Introduction By <u>Richard Fitzpatrick</u>)

$$\lambda_D = \sqrt{\frac{\varepsilon_0 K T}{q^2 n_0}}$$

PLASMA PROPERTIES
PLASMA FREQUENCY

Representing the oscillations of electric charges in conductive media like metals or plasmas

$$\omega_p = \sqrt{\frac{n\,e^2}{m\,\varepsilon_0}}$$

- electron concentration "n“
- elementary charge "e“
- electron mass "m"
- dielectric constant "ε_0“
- plasma frequency “ω_p”

Low-power ion source plasma, *T*e (30 000–40 000 K), while *T*i (500–1000 K).

The electron density *n*e amounts to about 1010 cm−3 =1016m−3 and higher.

(A Short Introduction to Plasma Physics
K. Wiesemann
AEPT, Ruhr-Universität Bochum, Germany)

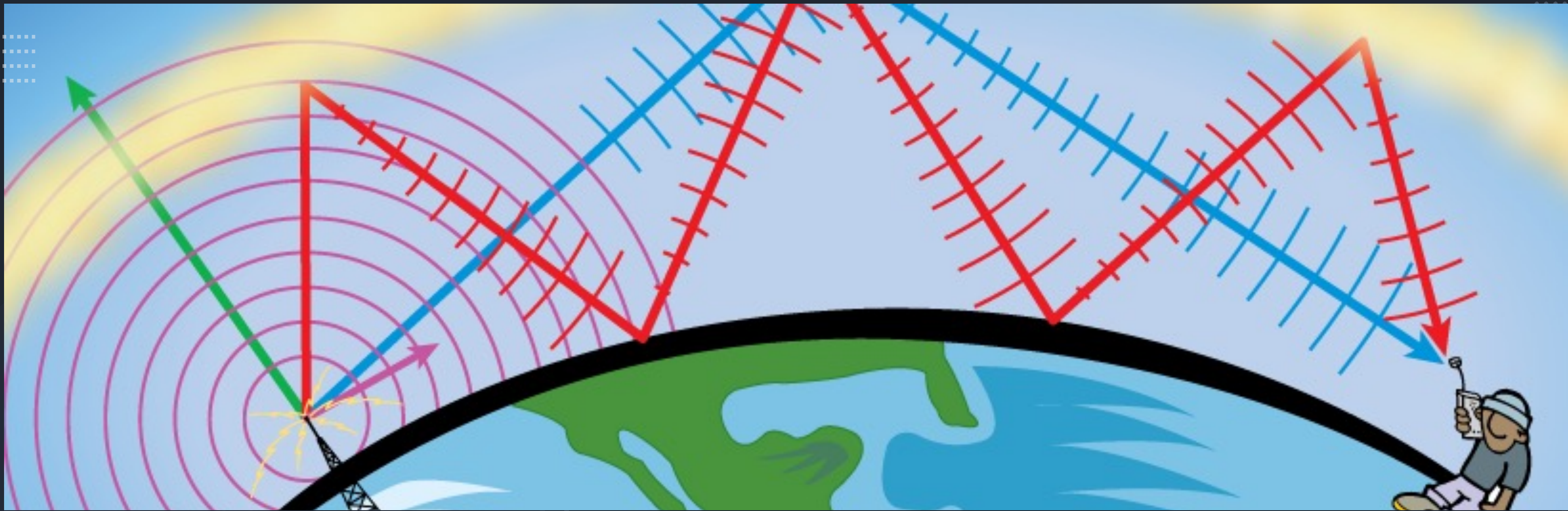


Image from: National Oceanic and Atmospheric Administration

IONOSPHERE

The ionosphere, found between 48 and 965 kilometers in the Earth's atmosphere, is influenced by solar radiation, creating positive ions and electrons. This plasma region, formed by ionization, plays a vital role in long-distance communication and satellite navigation, varying daily with solar intensity.

IONOSPHERE

APPLICATIONS:

- Long Distance Communications
- Amateur Radio
- Over-the-Horizon Radar
- Ionospheric Studies
- Satellite Navigation Systems
- Space Research

CLASSIFICATION OF PLASMAS

Based on Temperature:

Hot Plasma: Characterized by high temperatures, commonly associated with nuclear fusion experiments and the interiors of stars.

- **ω_p:** 1 GHz to 1 THz
- **λD:** 1 µm to 1 mm

Cold Plasma: Featuring lower temperatures, found in applications such as plasma technology in electronic device manufacturing.

- **ω_p:** 1 MHz to 1 GHz.
- **λD:** 1 mm to 1 cm.

(Image credit: NASA/SDO)

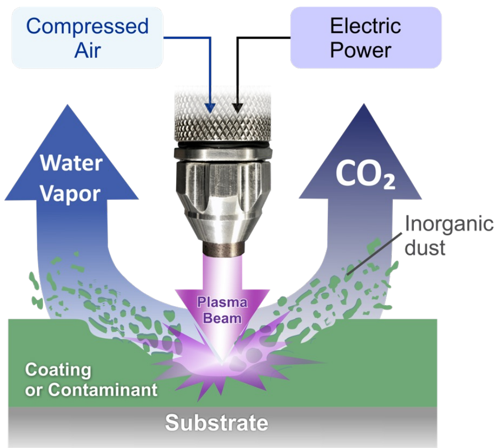


Image from: https://apsplasma.com/cold-plasma/

CLASSIFICATION OF PLASMAS

According to the Debye length (Lambda_D) and the number of particles on the Debye sphere (N_D):

Dense Plasma: Has a moderate Lambda_D and a moderate N_D value, indicating a moderate particle density in the Debye sphere.

- **ω_p:** Greater than a 1 THz
  - **λD:** 1 nm to 1 μm

Weakly Coupled Plasma: Characterised by a large Lambda_D value and a low N_D value, suggesting a low particle density in the Debye sphere.

- **ω_p:** 1 KHz to 1 MHz
  - **λD:** 1 m to 10 m

Strongly Coupled Plasma: Characterised by a small Lambda_D value and a high N_D value, indicating a high particle density in the Debye sphere.

- **ω_p:** Greater than a 1 THz
  - **λD:** 1 nm to 1 μm

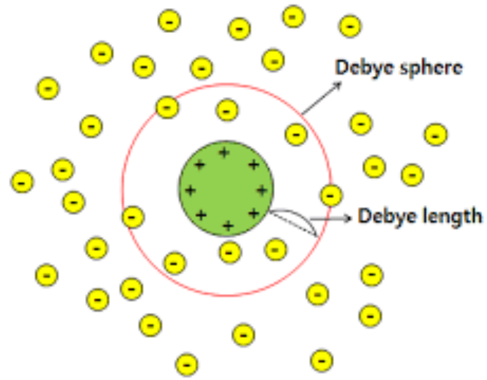


Image credit: IPR, Gandhinagar 382428, Gujarat (India)

CLASSIFICATION OF PLASMAS

Based on Energy Source:

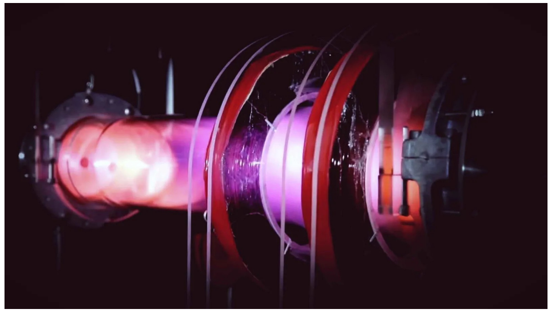
Astrophysical Plasma: Present in natural phenomena like the Sun and stars.

- **ω_p:** 1 MHz to 1 GHz
- **λD:** 1 km to 1 Mm

Lagoon Nebula, (wikipedia)

Laboratory Plasma: Artificially created in laboratory environments for specific studies and applications.

- **ω_p:** 1 KHz to 1 GHz
- **λD:** 1 mm to 1 m



Princeton´s Plasma Physics Laboratory (Smithsonian magazine)

CLASSIFICATION OF PLASMAS

Based on Application:

Industrial Plasma: Used in manufacturing applications, such as etching and thin film deposition in the electronics industry.

- **ω_p:** 1MHz to 1GHz
- **λD:** 1 mm to 1 cm

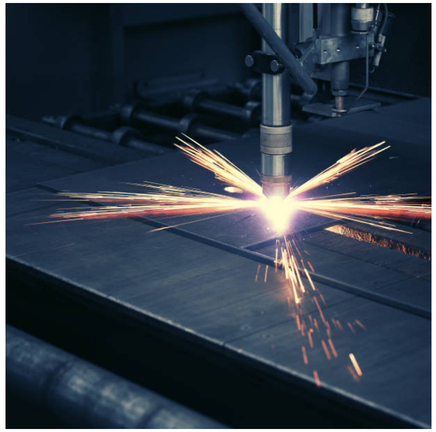


Image credit: Andrey Malinkin

Space Plasma: Present in space, affecting the interaction between charged particles and magnetic fields.

- **ω_p:** 1 KHz to 1MHz
- **λD:** 1 km to 1 Mm

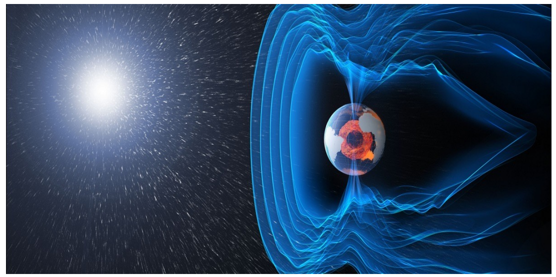


Image from: Austrian Academy of Sciences

CLASSIFICATION OF PLASMAS

Based on Geometry and Magnetic Configuration:

Magnetically Confined Plasma: Sustained by magnetic fields, common in nuclear fusion experiments.

- **ω_p:** 1 GHz to 1 THz
- **λD:** 1 µm to 1 mm

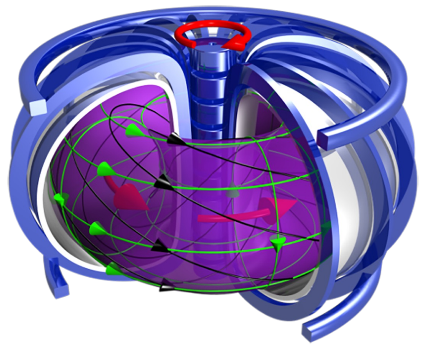


Image from: IAEA

Non-Magnetically Confined Plasma: Not subject to dominant magnetic fields, such as solar plasma.

- **ω_p:** 1 KHz to 1 GHz
- **λD:** 1 mm to 1 m

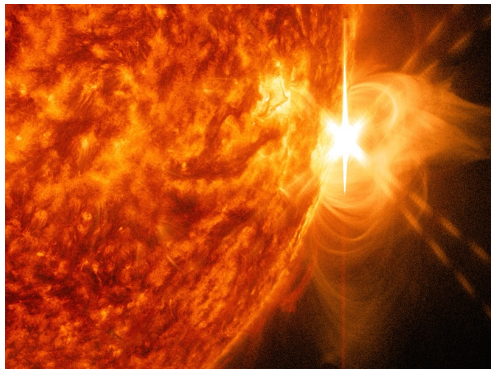


Image from: The Christian Science Monitor

CLASSIFICATION OF PLASMAS

Based on Species Composition:

Electron-Ion Plasma: Mainly composed of electrons and ions.

- **ω_p:** 1 GHz to 1 THz
- **λD:** 1 µm to 1 mm

Dusty Plasma: Contains suspended solid particles, such as charged dust.

- **ω_p:** 1 KHz to 1MHz
- **λD:** 1 cm to 1 m

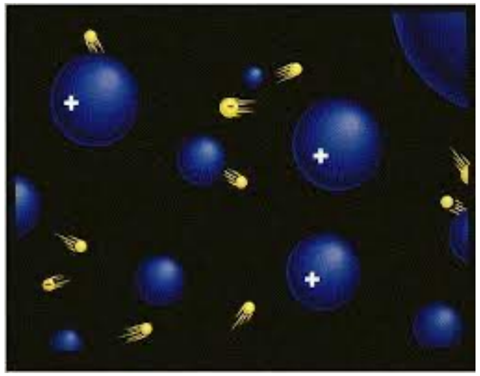


Image credit: Scientific & Academic Publishing

(https://www.plasma-universe.com/complex-dusty-plasmas/)

PLASMA APPLICATIONS

Fourth State Impact:

Fourth state of matter impacts various sectors.

Ionosphere's radio wave reflection aids long-distance communication.

Gas Discharge Innovations:

Lab gas discharges lead to gas light sources, advanced screens.

Controlled magnetic steel processing for cutting and welding.

Plasma Phenomena Contributions:

Plasma discharge aids in switching devices and space engines.

Plasma spraying innovations benefit surgery.

Thermonuclear Fusion Potential:

Toroidal chamber with magnets enables controlled fusion.

Promising for environmentally friendly power plants.

Diverse Applications:

Plasma tech in pollution control and waste treatment.

Space-specific engines and advancements in switching devices.

Medical applications in surgery and potential for sustainable energy.

(https://sciencealpha.com/es/plasma-properties-types-preparation-and-use)

Thank you for your attention