Introductory Lecture on Plasmas
EEG 783

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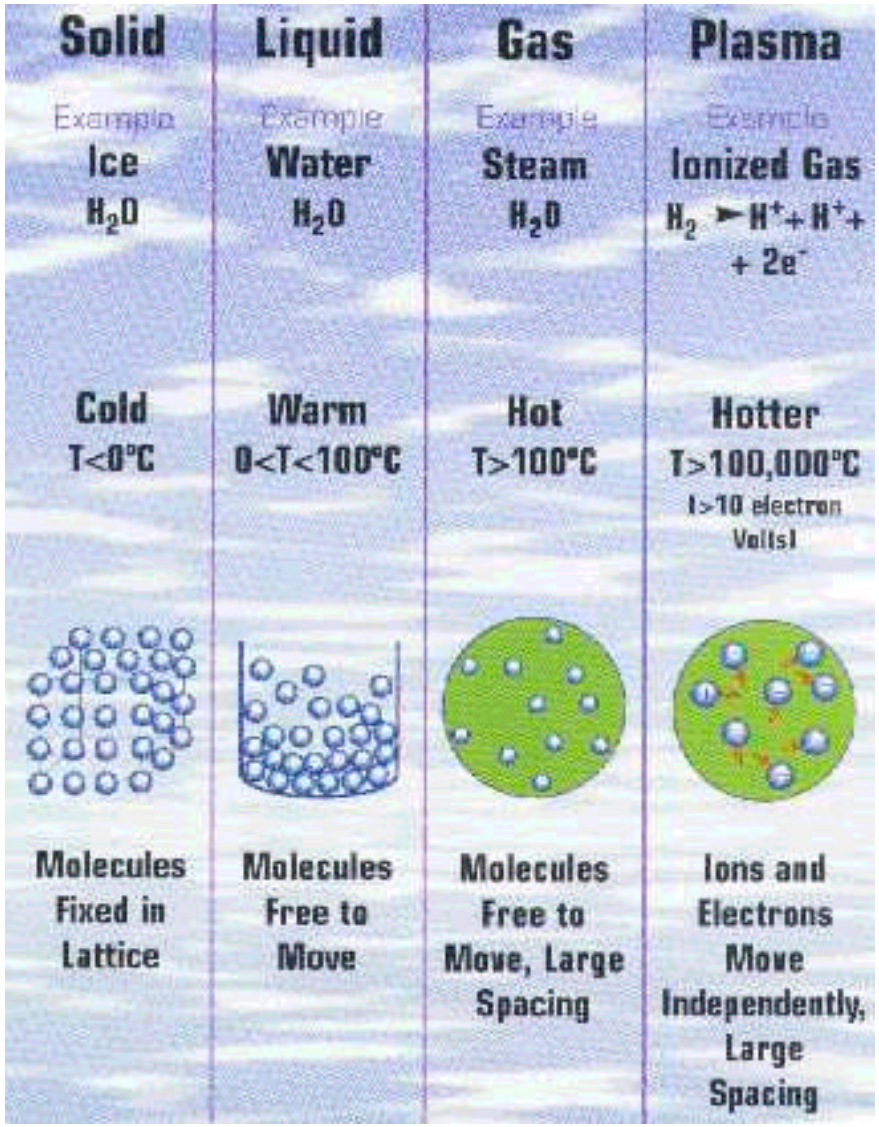
States of Matter

- Four Naturally Occurring States of Matter
  - Solids, Liquids, Gas, Plasmas
- Solids
  - Condense matter physics system
    - Quantum Mechanics
- Liquids, Neutral Gas
  - Fluid systems
    - Navier-Stokes Equation
- Plasmas
  - Electromagnetic System
    - Maxwell Boltzman Equations

What is a Plasma?

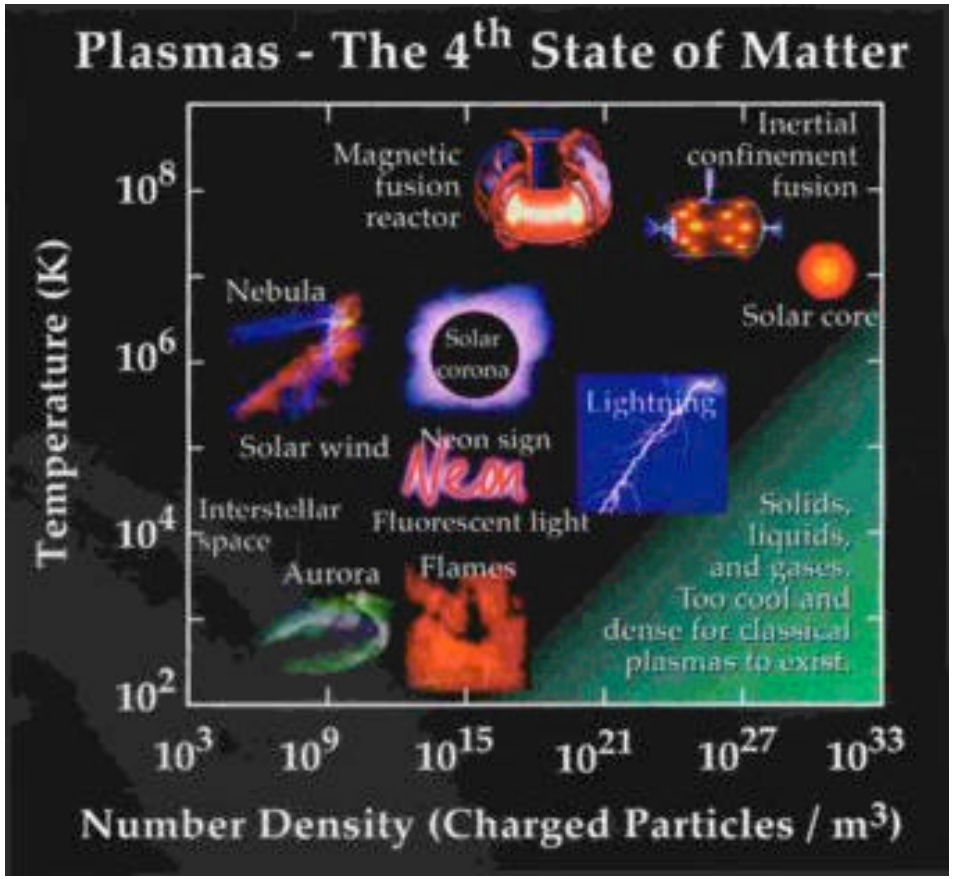
- Plasma?
  - Conductive assembly of charged particles, neutrals, and fields exhibiting COLLECTIVE effects
  - Carry currents
  - Generate magnetic fields
  - Respond to external electric and magnetic fields
  - May be an efficient source of radiation

Comparison of the Four States of Matter



- Solids, Liquids and Gases
  - Typically electrically neutral
  - Too Cold
  - Too Dense
- Plasma (Ionized Gas)
  - Collection of free moving electrons and ions
  - Large energies needed to strip electrons from atoms
    - Thermal
    - Electrical
    - Light - (UV or higher or intense light [Laser light])
  - Recombination - energy insufficient
  - Accelerated and steered with external E and B fields

Scaling



- Plasma Systems
  - Involve electrodynamic coupling across the micro-, meso-, and macroscale
  - Occur over most of the physically possible ranges in space, energy (temperature), and density
  - Chart yields only typical plasmas
    - Plasma crystals - ~0^{o}K
    - Cosmic Rays >10^9 ^{o}K
    - Some space plasma densities ~ 10^{-10} m^{-3}
- Enormous Range of Scales
  - Length, Density, Temp., Field Mag.

Mesoscale or Mesoscopic

- Definition
  - Middle, halfway, or intermediate
- Between Microscopic and Macroscopic
- Mesoscale
  - Condense matter physics
    - less than 10^{-7} meters
  - Space plasmas
    - greater than 10^{7} meters
- Relationship between Micro and Macro
  - Statistical
- Mesoscale
  - Statistical studies may not be good
  - Distinct structures and process may exist

Scaling Variations

- Scale Lengths - 10^{-12} to 10^{23} m
- Mass Density - 10^{-24} to 10^{13} kg/m^3
- Number Density - 10^{2} to 10^{36} m^{-3}
- Temperature (Thermal Energy) - ~0 eV to 10 keV
- Magnetic Fields - 10^{-6} to 10^{+6} G (10^{-10} to 10^{2} T)
- Plasma Lifetimes - ~10^{-12} sec. to infinity

Tables of Laboratory, Space & Astrophysical Parameters

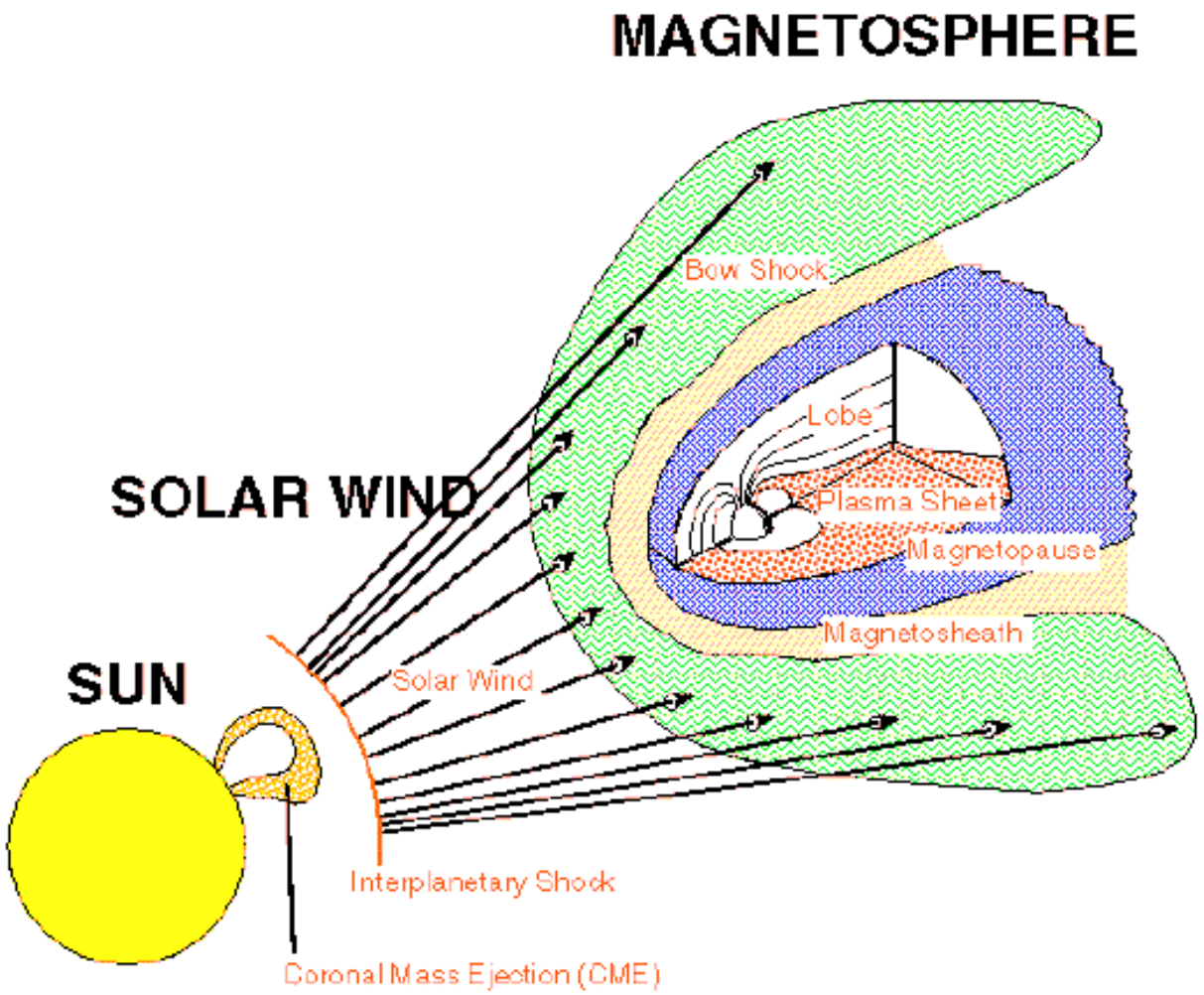
Scaling	Space Plasma	Size (km)	Laboratory	Size (mm)
	spacecraft	0.001		
Microscale	screening	1	sensor	1
	gyrations	100		
Mesoscale	filaments	1000	filaments	10
	plasma sheet	10,000		100
Macroscale	magnetosphere	100,000	chamber	1000
	heliosphere	1,000,000		

Parameter	Ionospheres and Magnetospheres	Interstellar Regions	Stellar Winds and Stellar Spheres	Stars
Plasma Density (cm^{-3})	<0.0001 - 100,000	0.001 - 10	0.001 – 1000	log 7 – 30
Neutral Density (cm^{-3})	0 – 100,000	0.01 - 1	0.1 – 100	0
Thermal Energy (eV)	<1 – 10,000	1 – 10,000	1 – 100	0.5 – 2000
Bulk Speed (km/s)	0 – 1500	1 - 30	10 – 1000	0 - 500
Magnetic Field (10^{-9} T)	1 – 10,000	<0.1 - 1	0.01 - 50	log 5 - 9

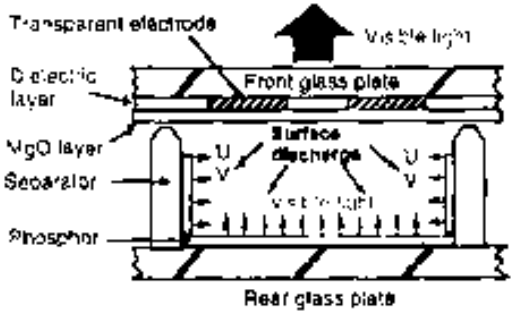
Star Formation in Eagle Nebula

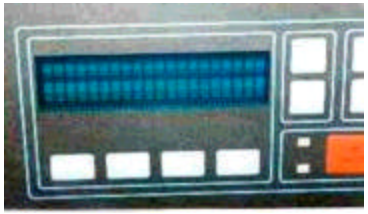
Space Telescope Science Inst. NASA

Space Plasma Physics - Diagram



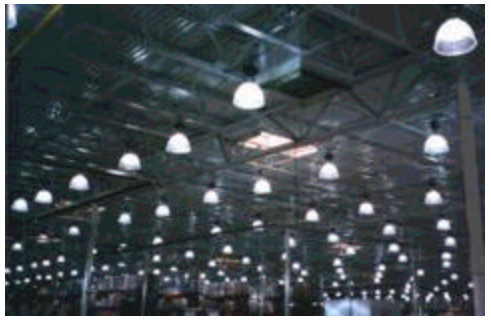
Plasmas for Homes





Plasma discharge high-brightness alphanumeric readout

- High Efficiency Lighting
- Manufacturing of semiconductors for home computers, TVs and electronics
- Flat panel displays
- Surface treatment of synthetic cloth for dye adhesion

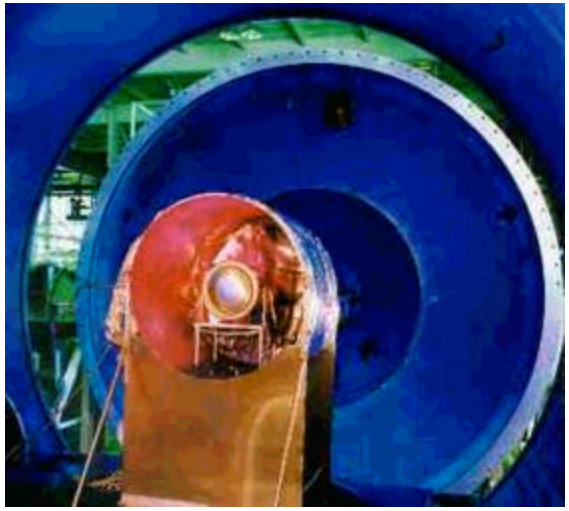


Plasma arc lamps

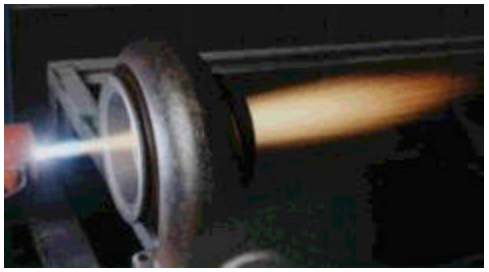
OSRAM Sylvania

Plasmas for Transportation

Microwave generated plasma around a catalyst for removal of NOx and Co from engine exhaust



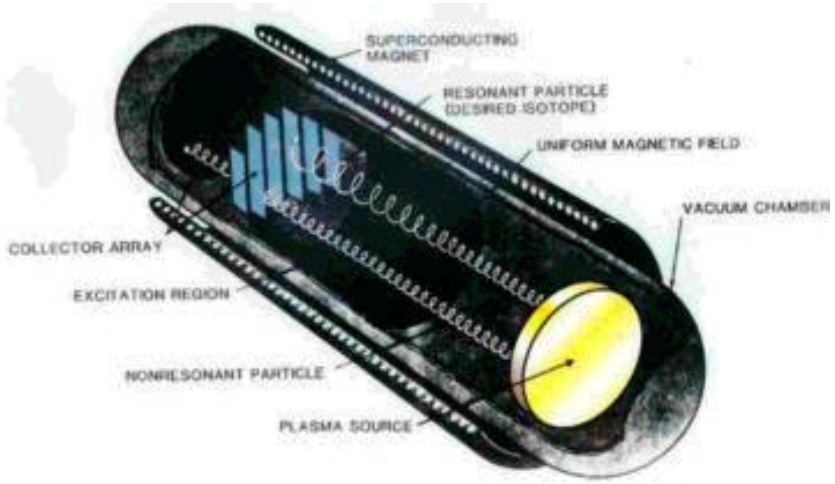
Plasma Thrusters for Spacecraft -electrostatic ion thruster (NASA)



Plasma spraying of high temperature resistance surface coatings for a diesel engine turbocharger housing

- Plasma spray of surface coatings
  - Temperature resistance
  - Wear resistance
- Treatment of Engine Exhaust
- Ion Thrusters for Space Flight

Business Applications



Isotope Separation

Plasma sources and magnetic field control of gyrating charged plasma particles are important for the separation of stable isotopes for medical and industrial use.

Plasma enhanced chemistry

Surface cleaning

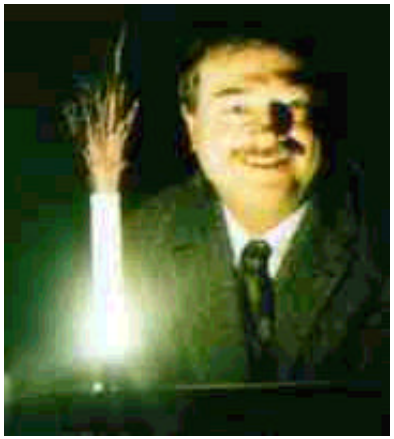
Processing of plastics

Spraying of materials

Chemical analysis

- High efficiency lighting
- Sterilization of medical tools
- Semiconductor production

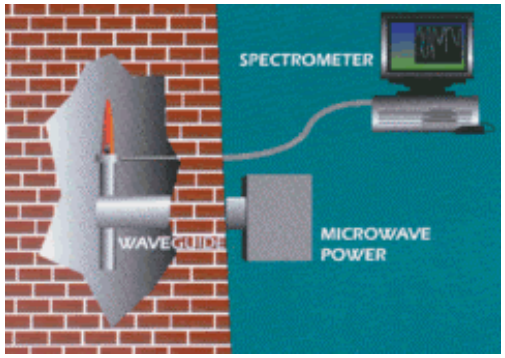
Plasma for the Environment



Iron filings injected into a plasma release atoms that become excited and emit light which can be readily analyzed.

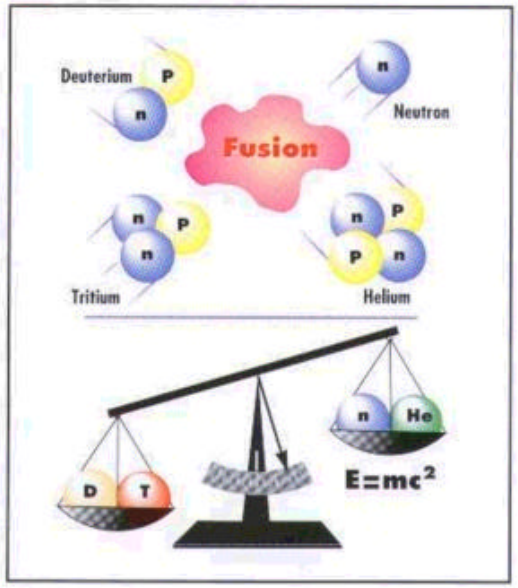
Plasma-based sources can emit intense beams of UV & X ray radiation or electron beams for a variety of environmental applications such as water sterilization.

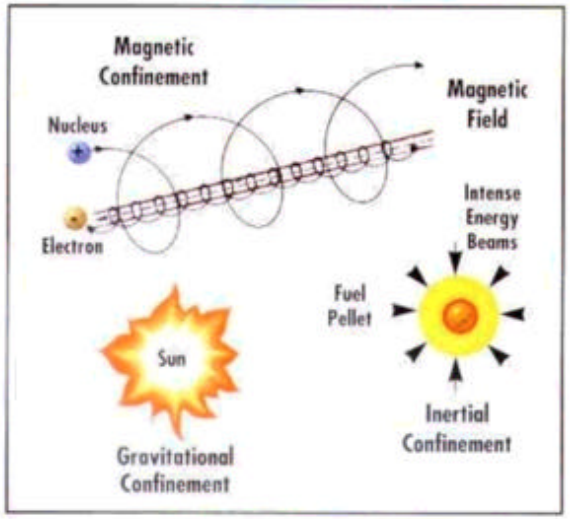
- Atomic Metal Emission Monitoring
- Water Purification Systems
- Real-time Clean Fuel Generation
- Clean up Hazardous Chemical Waste or Enable Soil Remediation



Pollution Monitoring: Exhaust gas flow from a furnace passes through a microwave plasma, becomes excited and emits light which is analyzed by a spectrometer to identify any hazardous elements.

Plasma for Energy

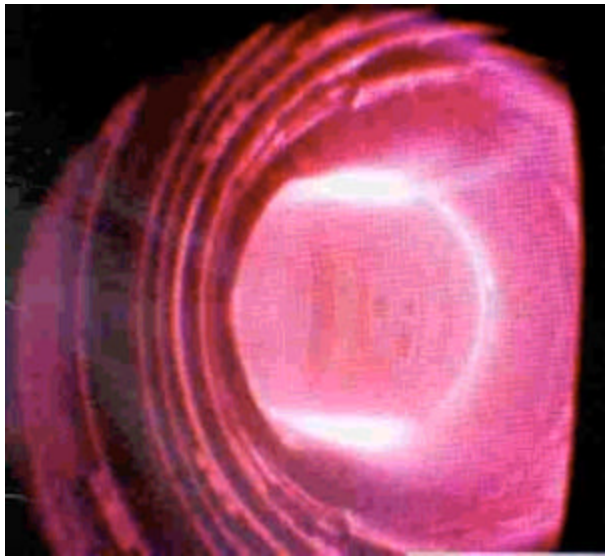




- Fusion
  - Light atoms combine with a release of energy
  - Inertial
  - Mag. Confinement

X-ray view of Sun from Yohkoh, ISAS and NASA

Laser plasma interaction during inertial confinement fusion. (Univ. Rochester)



Plasma radiation within the Princeton Tokamak.

Plasmas and Manufacturing 1

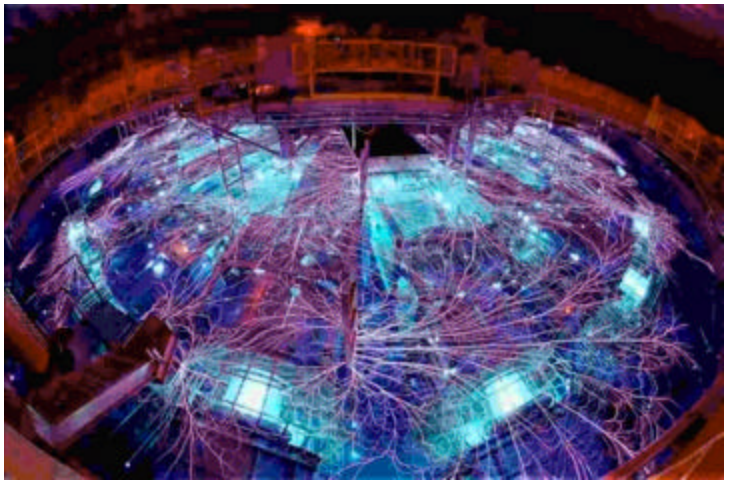
- Surface Treatment
  - Ion implantation
  - Hardening
  - Welding, cutting and drilling
- Volume Processing
  - Flue gas treatment
  - Metal recovery waste treatment
- Chemical Synthesis
  - Plasma spraying
  - Diamond film deposition
  - Ceramic powders
- Light Sources
  - High Intensity
  - Discharge lamps
  - Low pressure lamps
- Lasers
- Flat-Panel Displays
  - Field-emitter arrays
  - Plasma displays
- Radiation Processing
  - Water Purification
  - Plant growth
  - Meat pasteurization
- Isotope Separation

Plasmas and Manufacturing 2

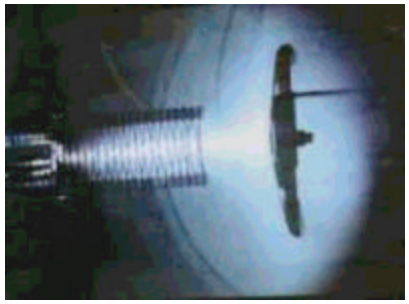
- Switches
  - Electric power
  - Pulsed power
- Energy Converters
  - MHD Generators
  - Thermionic energy converters
- Beam Sources
  - fine mirror polishing
  - Impulse surface heating
  - Free Electron Lasers
- Material Analysis
- Propulsion
- Medicine
  - Surface treatment
  - Instrument sterilization
  - Applications in medical implants and prosthetics
- Plasma Chemistry - surfaces
  - Etch
  - Coat
  - Clean
- Surface Treatment of Fabrics (Polymer fabrics and Wools)
  - Enables
    - wettability
    - wickability
    - printability

Plasmas in Defense

- Plasma ion implantation for hardening surfaces
- Destruction of Chemical Warfare Agents
- Low Density Plasma Mirrors
- Stockpile stewardship
  - Z-Pinch
  - National Ignition Facility

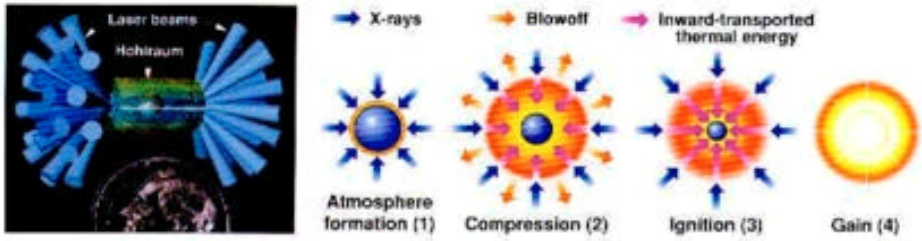


Z-Pinch Sandia Natonal Lab.



Plasma ion implantation can produce hardened surfaces for many defense and civilian applications.

Mirrors using low-density plasmas are attractive candidates for electronic steering of shipboard radar for the 21st century (Naval Research Laboratory).



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Conclusion

- Fourth State of Matter
- Makes up 99% of our universe
- Numerous Applications
- Multi-Scale
- Web Site Address for more information
  - http://www.plasmas.com