Integrating Plasma Physics into the High School Curriculum

This outline uses the following format:

Curriculum topic
Plasma related topic
Demonstrations, labs, problems, etc

States of Matter

Plasma is defined as one of the four states of matter

Demo: fluorescent bulb, plasma globe

Electrostatic or Electromagnetic Fields

Long range nature of the electrostatic interaction

Lighting a fluorescent light bulb with a Van de Graaf generator

Magnetic Interactions

Sources of Magnetic field

Observations of magnetic field of a fluorescent bulb or other plasma sources using a magnaprobe and/or a Hall probe
web site for basic magnetism:
http://ippex.pppl.gov/ippex/module_4/

Charged Particles in Magnetic field

- ◊ **Aurora lights, solar wind, Van Allen belt**
- ◊ **Cyclotron frequency in plasmas with magnetic field**
- ◊ **Effects of magnetic field on plasma: magnetic confinement (magnetic bottle, Tokamak, magnetrons)**

  Fluorescent light or plasma tube with magnetic field
  Virtual Tokamak
  http://ippex.pppl.gov/ippex/pages/virtual_tokamak.html

Conservation of momentum

Collisions in plasma

Collisions between charged particles can be easily modeled using the Interactive Physics software from Vernier

Energy:
Kinetic Theory

Plasma Temperature

Electron (ion) temperature and velocity calculations for various plasma sources

Diffusion in plasma

Observing the afterglow

Heat Capacity

Loss of plasma energy to chamber walls

"Cool" or "hot" fluorescent light or any other plasma source

Energy Transfer by Radiation:

Microwaves and radio waves for heating and sustaining plasma

Fluorescent light in a microwave oven - estimate plasma density

Radiation emitted from plasma sources

Plasma globe, fluorescent light, etc. – estimate plasma temperature (electron)

Current Electricity

Plasma current and resistivity

Estimate conductivity/resistivity of plasma sources, drift velocity, etc

Measure the current in a fluorescent light bulb or plasma globe

Dielectrics and Plasmas

Breakdown

Measure breakdown voltage for a fluorescent light bulb or any other dc discharge

Observe and explain the structure of dc discharge

Electromagnetic Induction

Induced Plasma Currents

Current – drive devices, "bootstrap" current

Physical Optics

Emission Spectroscopy of Plasma

Identifying the gasses in a glow globe, a fluorescent light bulb, or another plasma source

Interferometry of Plasma

Measuring the index of refraction using microwave interferometry

Interaction of Radiation with Matter

Discussion of reflection, transmission, and absorption in terms of plasma frequency

Examples of interaction of radio waves with ionosphere

Atomic Physics

Emission Spectrum of Plasma

Compare the spectra of various laboratory plasma sources and the sun; use spectroscopes with the fluorescent light bulb, plasma globe, He, Ne, H, etc. discharge tubes, etc.

Demonstrate the structure of a dc glow discharge in a fluorescent light bulb or another dc glow discharge; discuss in terms of mechanisms of producing line spectra

Nuclear Physics

Fusion of course, but you all know about that

Velcro and magnet demos, etc

Definition of Plasma:

A plasma is a quasineutral gas of charged and neutral particles which exhibits collective behavior.

F. F. Chen, Introduction to Plasma Physics and Controlled Fusion, Second Edition, Volume 1, Plenum Press, 1984

Neutral gas – dominated by collisions

Plasma – electromagnetic interactions - long range - collective behavior

EXAMPLES:

Plasma	Electron temperature, K	Electron density, m^{-3}
Sun: center	$2x10^7$	10^{32}
Surface	$5x10^3$	10^{12}
Corona	10^6	10^{11}
Fusion experiments	10^9	10^{20}
Lightning bolt	$3x10^4$	10^{18}
Glow discharge	$2x10^4$	10^{15}
Ionosphere	$2x10^3$	10^{11}
Ordinary Flame	$2x10^4$	10^9
Interplanetary space	10^2	10^6
Solar wind	10^5	5

Applications:

A. Gas Discharges

Lasers

1. Spark gaps

Welding arcs
Lightning
Fluorescent lights
Flat-screen displays
Etching
Film deposition and cleaning

B. Controlled Thermonuclear Fusion

C. Space and Astrophysics

D. Solid State Plasmas

Characteristics of Plasma

Bulk Properties

Electrical Resistivity and Conductivity

Conductivity $\sigma = \frac{1}{\rho} = \frac{L}{RA}$

Current density J = env , (A/m^2),
where n - # electrons (ions) per m^3, v – drift velocity, and e- electron charge

$J = \sigma E$

Electron accelerating between collisions: a = eE/m,
where m is the mass of an electron.
Then v = eEt/m , where t – time between collisions, then conductivity

$$\sigma = \frac{e^2 nt}{m}$$

General current density in the presence of magnetic field:

$\mathbf{J} = \sigma[\mathbf{E} + (\mathbf{v} \times \mathbf{B})]$

Bulk Force on Plasma:

$F = J \times B$

$F = \sigma(\mathbf{E} \times \mathbf{B}) - \sigma B^2 \mathbf{v} + \sigma(Bv)\mathbf{B}$

Ohmic Heating of Plasmas

The electrons acquire energy from the electric field and dissipate it in elastic and inelastic collisions.

Power density: $p = \rho J^2 = \sigma E^2$

Plasma Shields Out External Potentials

Characteristic length, Debye length

$$\lambda_d = \left(\frac{kT\varepsilon}{ne^2}\right)^{\frac{1}{2}} \text{ (m)}$$

Plasma Frequency

Using Gauss's Law, the electric field at a distance x from a flat electrode in a plasma

E = enx/ε (V/m)

The equation of motion for an electron in this field is

ma = -eE

$a = -\left(\frac{ne^2}{m\varepsilon}\right)x$ which is an equation for simple harmonic motion a = -kx

Plasma frequency $\varpi = \left(\frac{ne^2}{m\varepsilon}\right)^{1/2}$ (rad/s)

$\nu = 8.980n^{1/2}$ (Hz)

Cyclotron Frequency

$$\varpi_c = \frac{eB}{m}$$

To qualify (for being plasma) plasma must satisfy the following conditions:

$\lambda_d << L$

$\omega t > 1$

# of particles in a Debye sphere >>> 1

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Glow Discharge

Use as many methods as you can to estimate plasma temperature and hence the speed of the electrons in this chamber.

Observation	Method	Estimate

Microwave Plasma

1. What ignites the discharge in the bulb?

2. Suggest a mechanism for the transfer of energy from the microwaves to the plasma.

3. Why is microwave radiation suitable for this?

4. How is this effect related to the common wisdom of not putting metal into a microwave?

5. Why don't plastic or ceramic containers glow in a microwave?