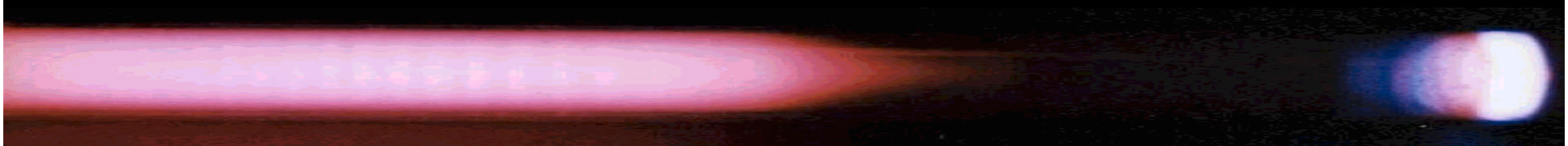
The Use of a Glow Discharge Source in Teaching Introductory Physics



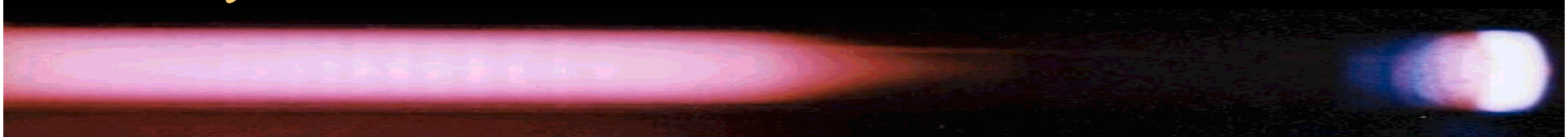
Sophia Gershman

Watchung Hills High School

Andrew Post-Zwicker

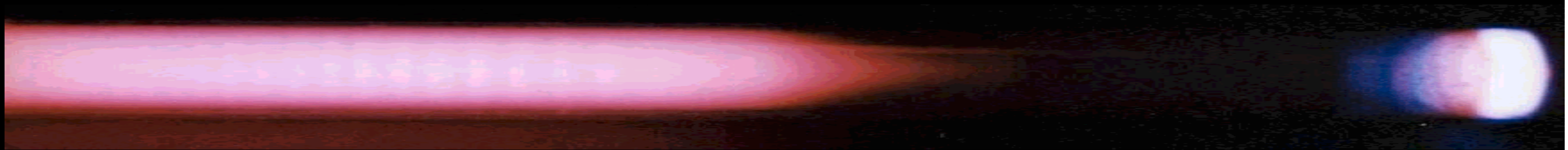
Princeton Plasma Physics Laboratory

Expose the true Face of Physics - "What question have you asked at school today?"
R. Feynmann



Plasma experiments are superb for generating questions, stimulating curiosity[1], increasing personal relevance of learning [2].

1. B. A. Crawford, J. S. Krajcik, R. W. Marx, "Elements of a community of learners in a middle school science classroom, *Sci Ed* **83**:701-723(1999)
2. M.P. Silverman, "Self-directed learning: A heretical experiment in teaching physics *Am. J. Phys.* **63**(6),(1995)



Share the Beauty of Physics

Too small…(too simplistic)

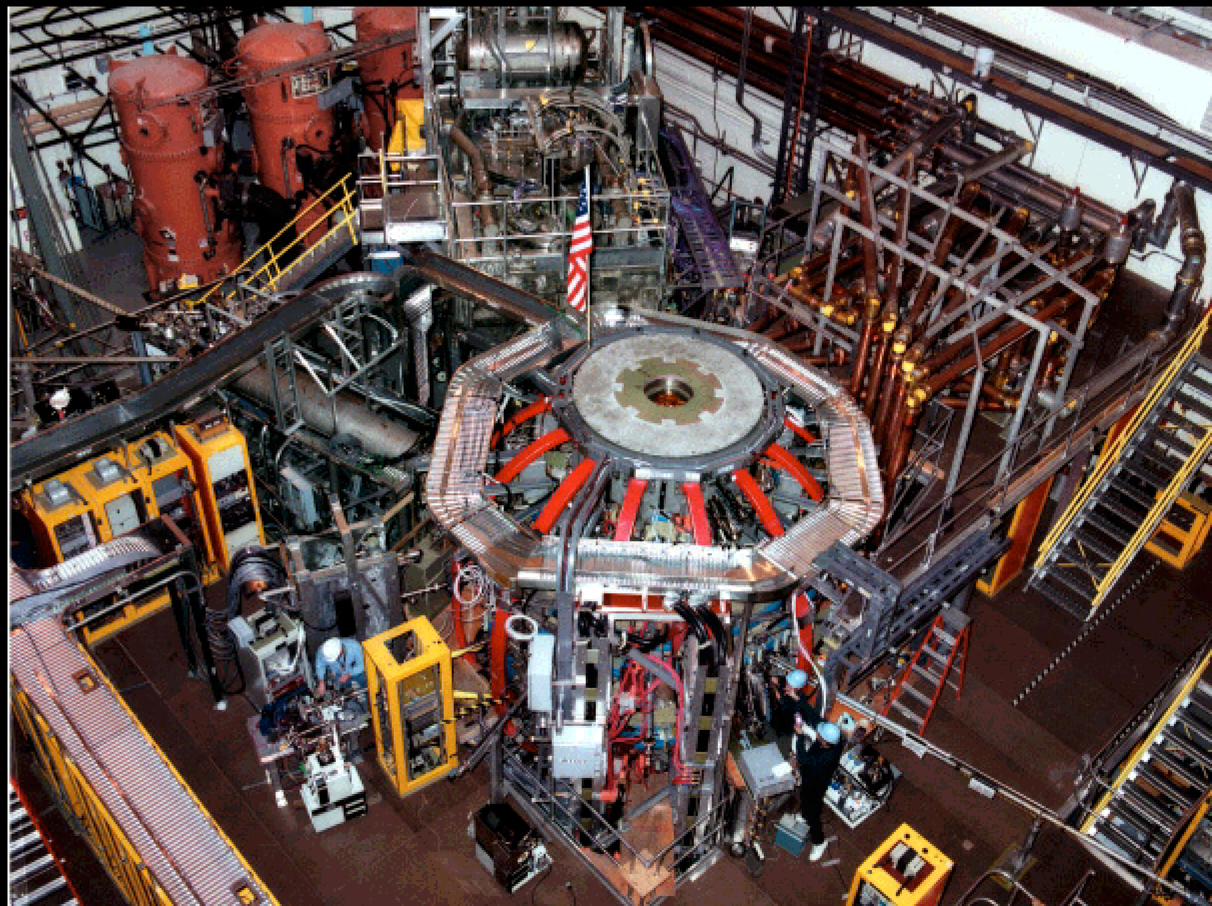
"Physical concepts rarely occur in isolation. …Thus, simple physical demonstrations often do not intuitively compliment a physics student's practical experience." - A student's comment.

Nature does not come in "single concept" packages. Leave it for the end of the year?

"The glow emanating from a fluorescent tube is complicated, but so is reality" - A student's comment

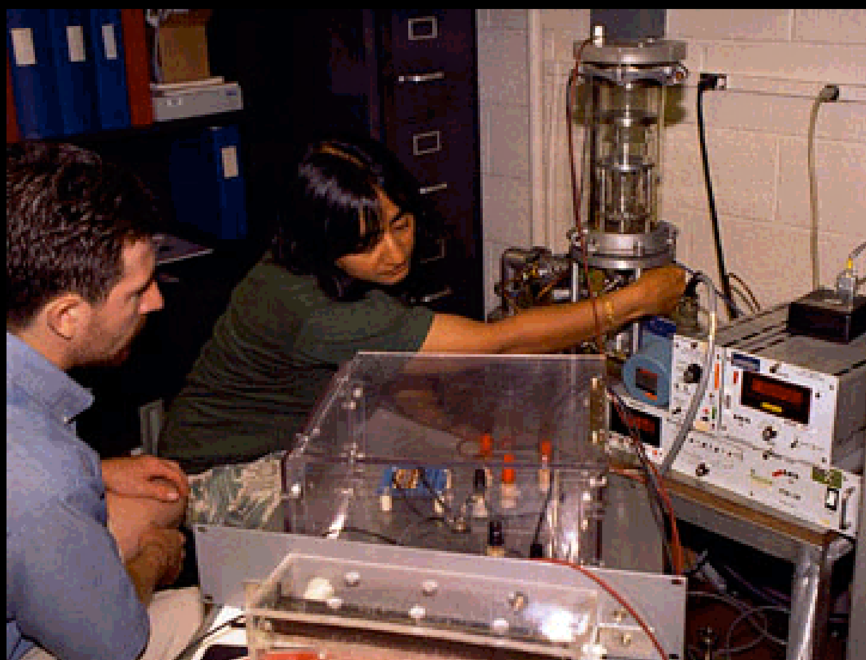
Photos by Jan Curtis, 2001

Too big … for kids

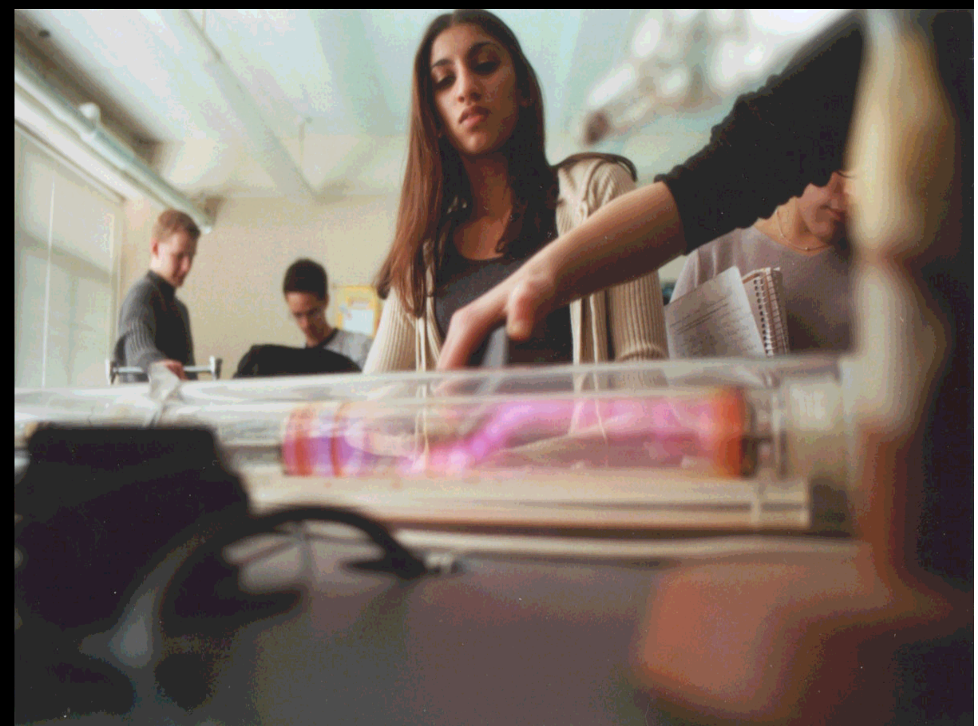


Photos courtesy PPPL

...Ahh!
Just the Right Size Plasma!



PPPL, Plasma Camp, 1998



Watchung Hills High School, 2001

Plasmas provide a rich learning environment [3]

Students' comments:

"It brings to mind "classic" physics experiments with electricity, glow tubes, and boxes with dials."

"It is different, and that makes it good"

"I like plasma labs because they connect to more complicated experiments, like the Princeton Plasma Lab."

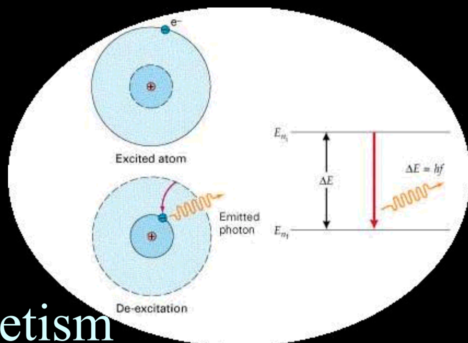
Tabletop plasma experiments are

- cheaper than a supercollider
- safer than a nuclear reactor
- richer than rolling balls

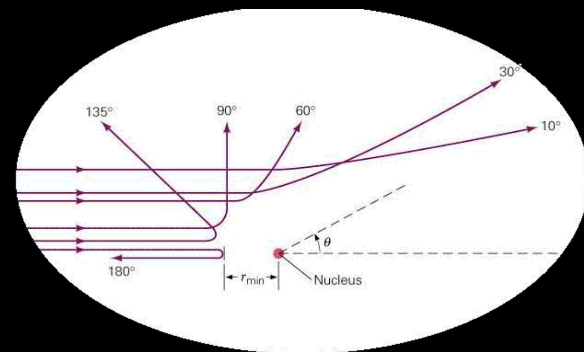
3. W. L. Shapiro, "Collaborative Problem Solving in a Large Scale Space Science Simulation", Presented at the Annual Meeting of the American Educational Research Association, Montreal, Quebec, Canada, April 19-23, 1999

Using Plasma to Teach Physics: An Integrated Approach

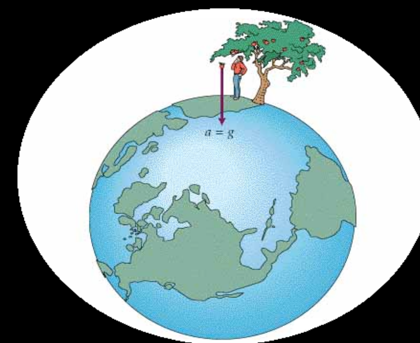
•Atomic and Quantum Physics



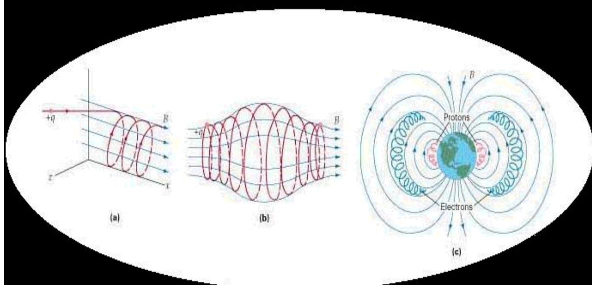
•Conservation of



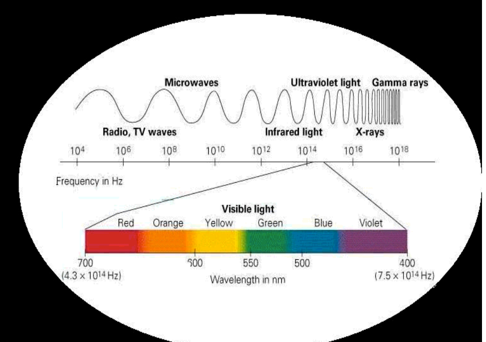
•Dynamics



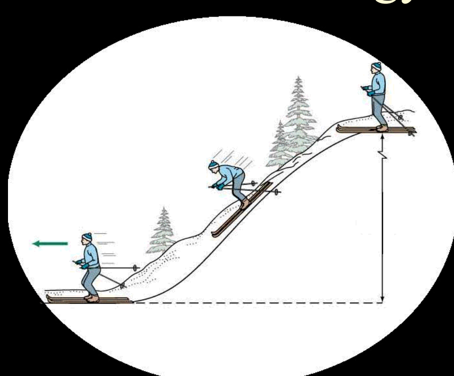
•Electromagnetism



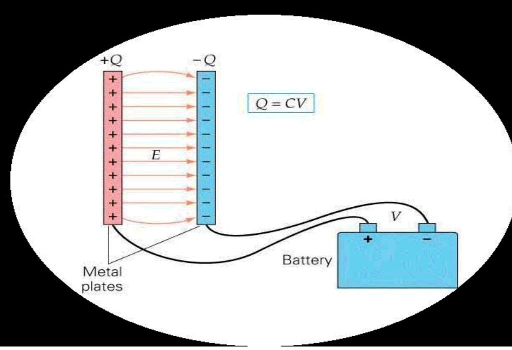
•Electromagnetic waves



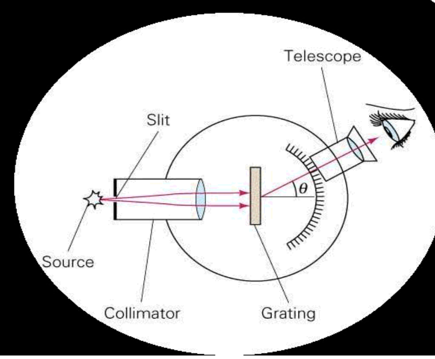
•Conservation of Energy



•Electrical Circuits

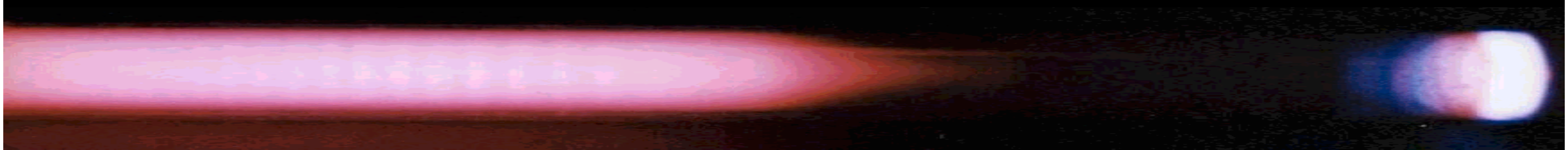


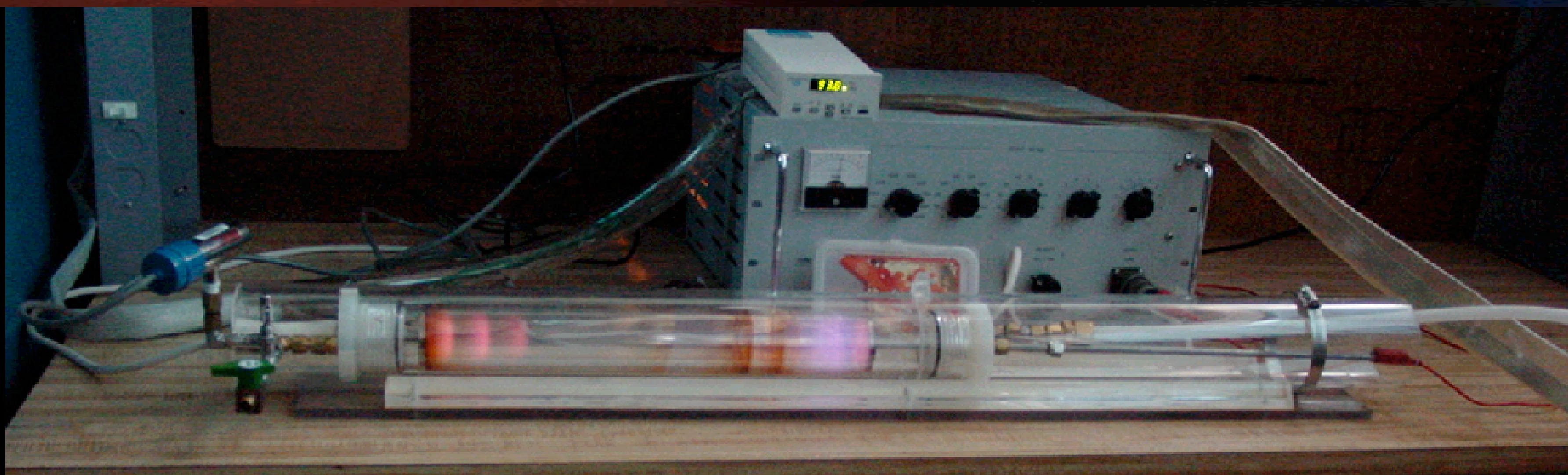
•Optics



Illustrations from Wilson, Buffa, College Physics, Prentice Hall

The Plasma Chamber

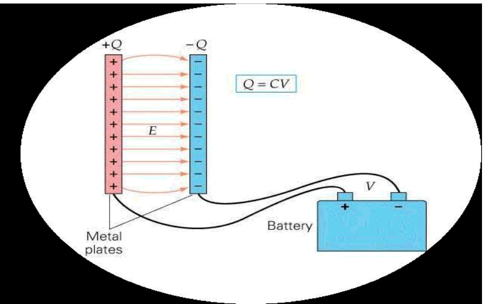


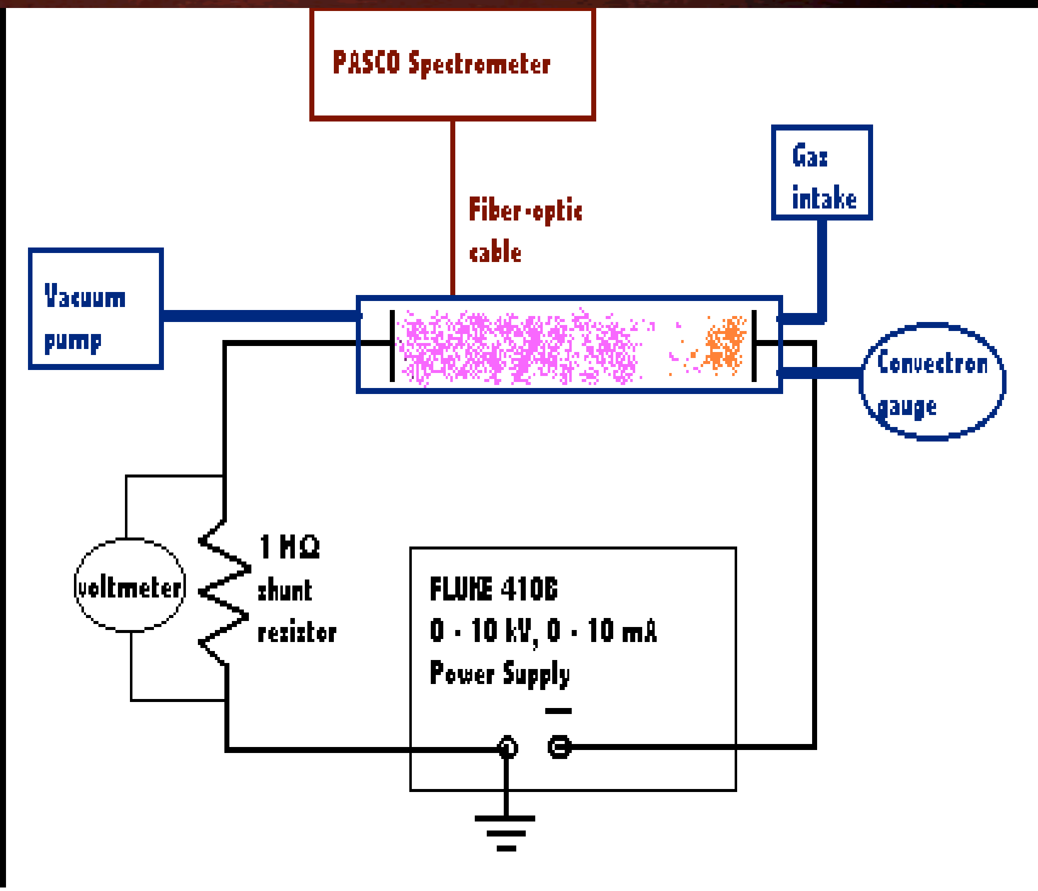


A portable science laboratory complete with
- high voltage,
- vacuum,
- lights, dials, and wires, and ….
- a ***glowing plasma***

The Plasma Chamber

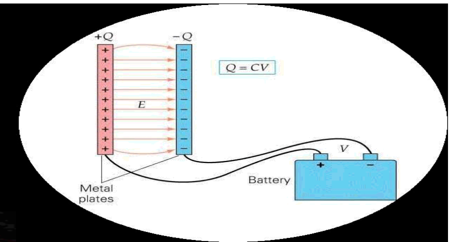
•Electrical Circuits





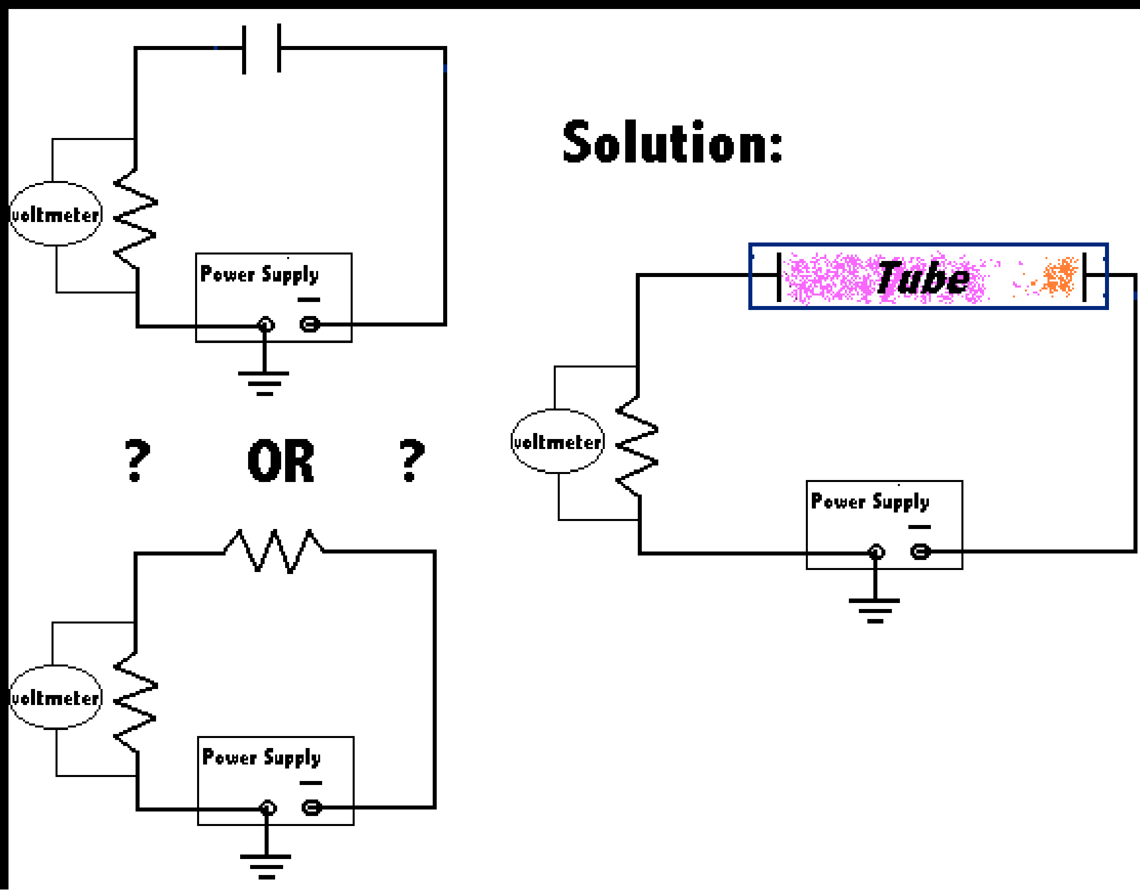
- •Circuit Diagrams
- •V-I characteristics
- •Capacitors, Resistors
- •Electrical Breakdown
- •High Voltage Safety

•Electromagnetism: Electrical Circuits

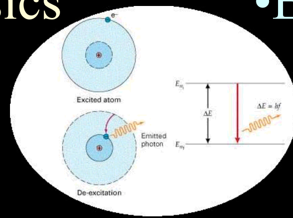


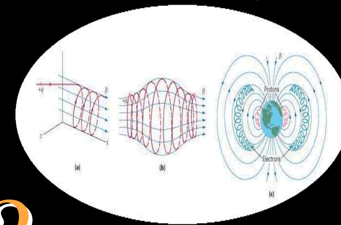
Example Question: Capacitor or Resistor?

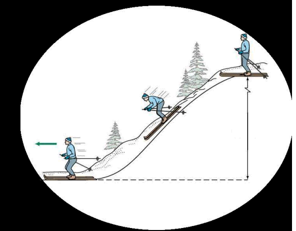
Answer: When?



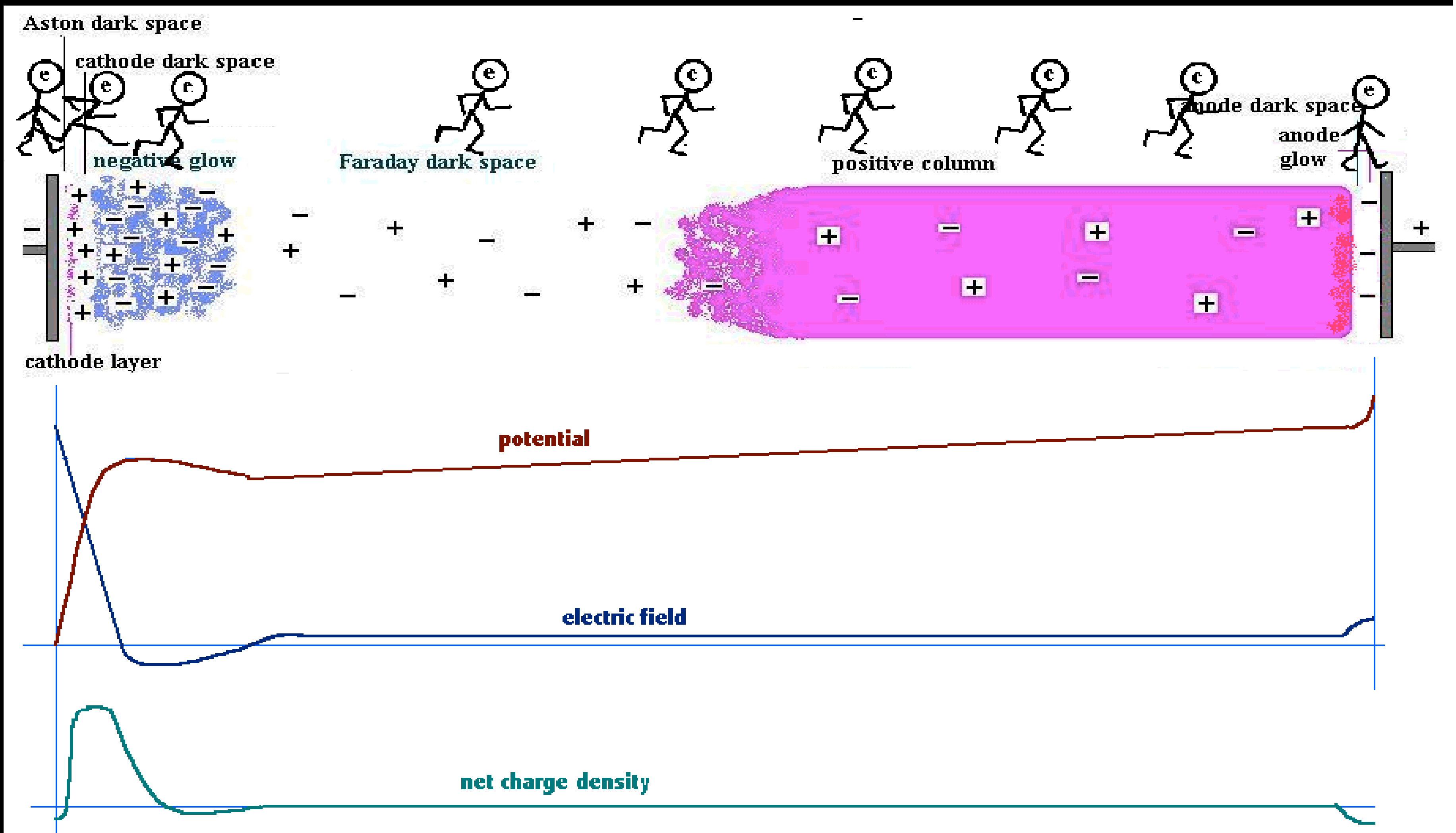
•Atomic and Quantum Physics •Electromagnetism •Conservation of Energy



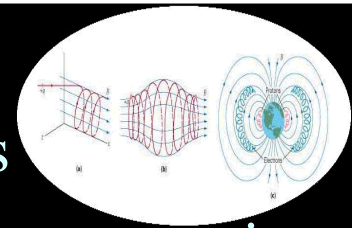




Question: Is it a Capacitor?



Electric Field and Potential: Students' Calculations



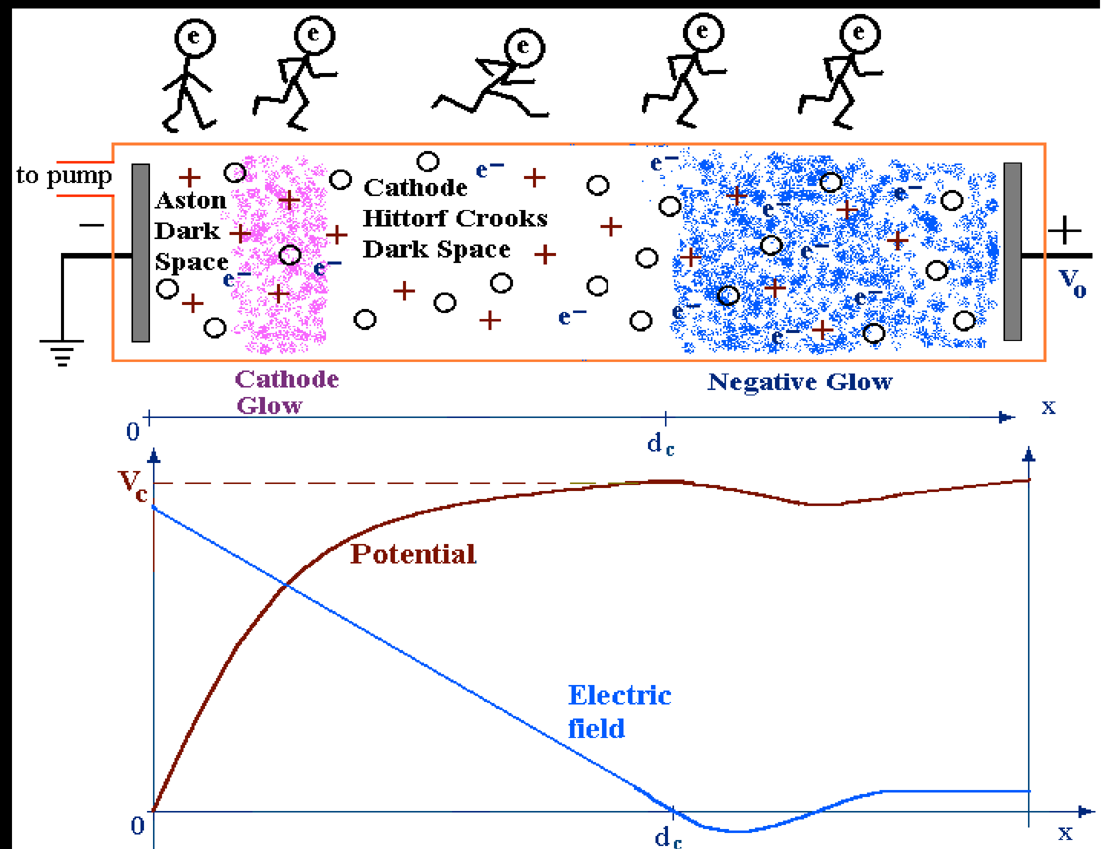
- Calculus
- Electromagnetism

Experimental results for electric field near the cathode (up to d_c):

$E = C(d_c - x)$,

x - the distance from the cathode, C – a constant

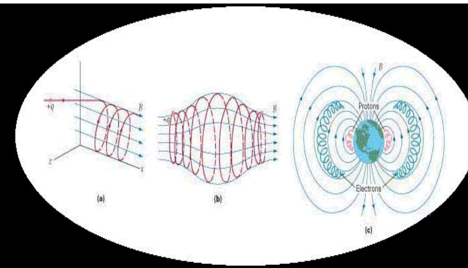
Students calculate the potential as a function of the distance from the cathode:



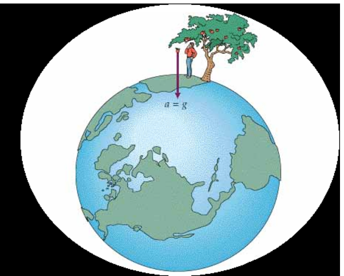
$$V(x) = \int_0^x E\,dx = \int_0^x C(d_c - x)\,dx = C\left(x d_c - \frac{x^2}{2}\right)$$

What's a "space charge"?

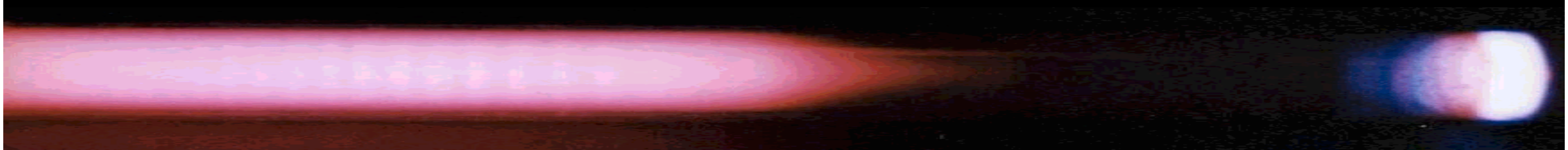
Hot or Cold?

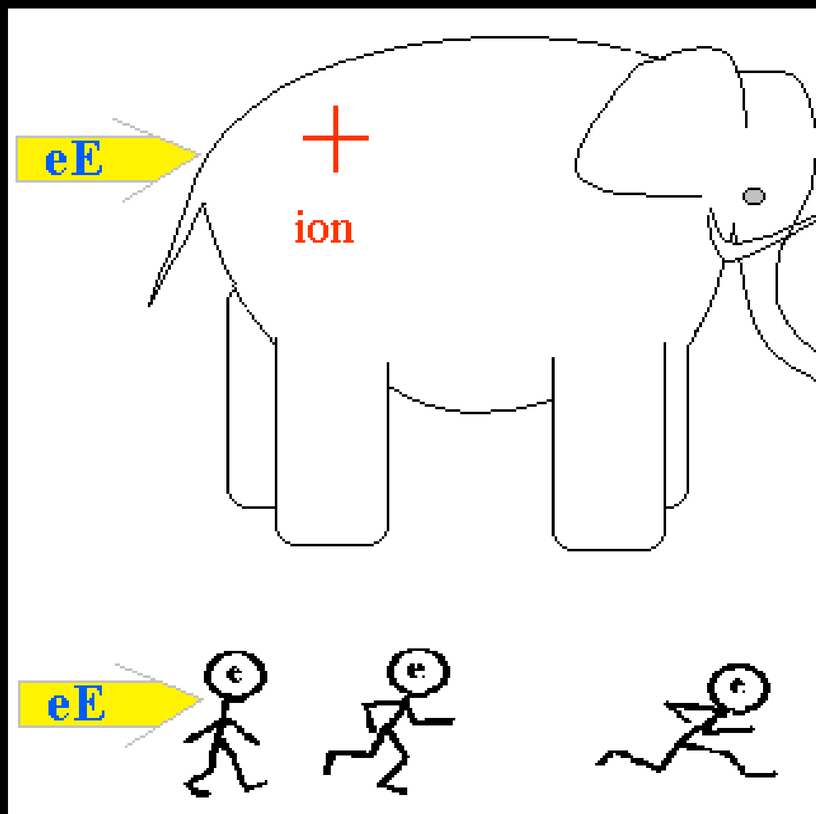


•Electromagnetism



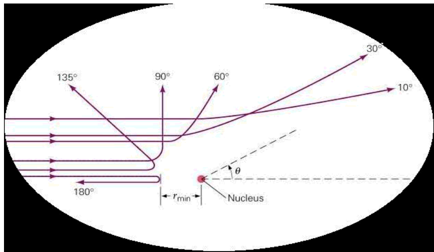
•Dynamics



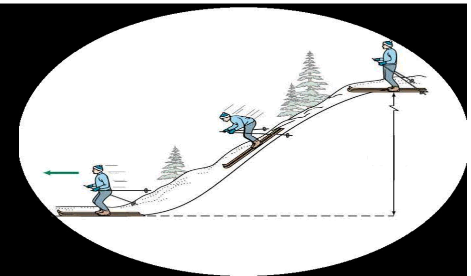


$$m \frac{dv}{dt} = eE$$

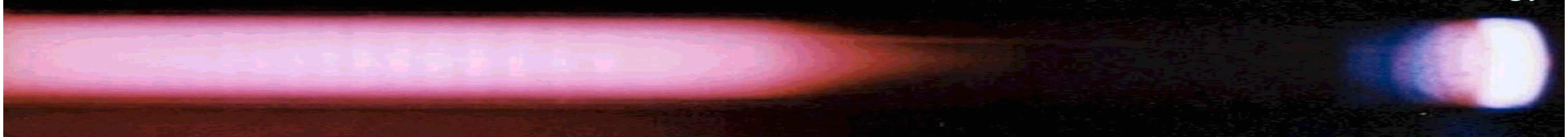
Hot or Cold?
Students' Calculations



•Conservation of Momentum



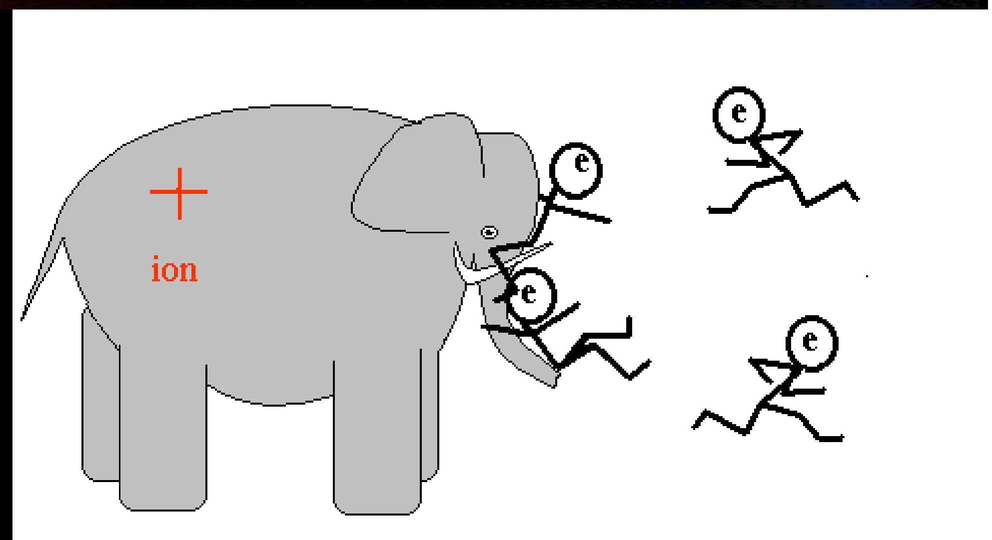
•Conservation of Energy



Average amount of energy transferred from an electron to a neutral or an ion in an elastic collision:

$$E_{t,avg} = E_1 \frac{2m_1 m_2}{(m_1 + m_2)^2}$$

$$E_{t,avg} = E_1 \frac{2m}{M}$$

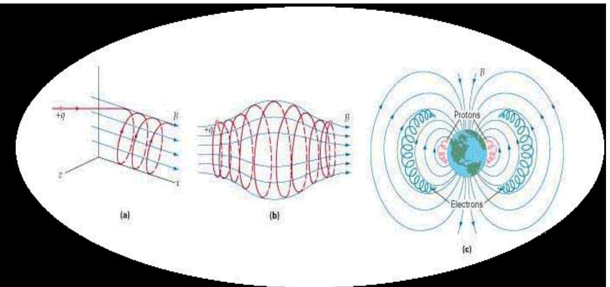


For Ar atoms:

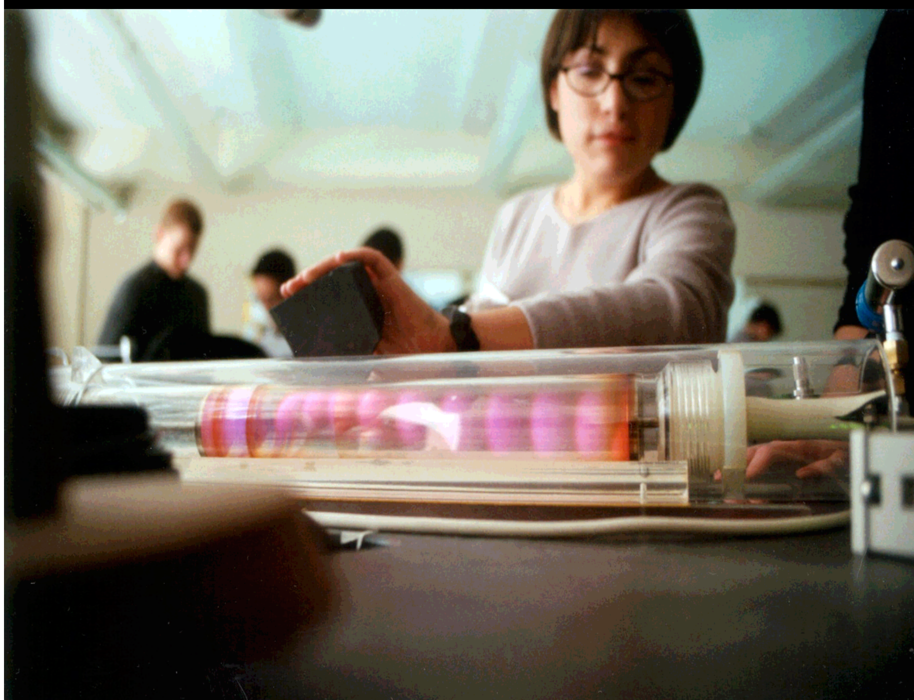
$$\frac{E_t}{E} \approx \frac{1}{40,000}$$

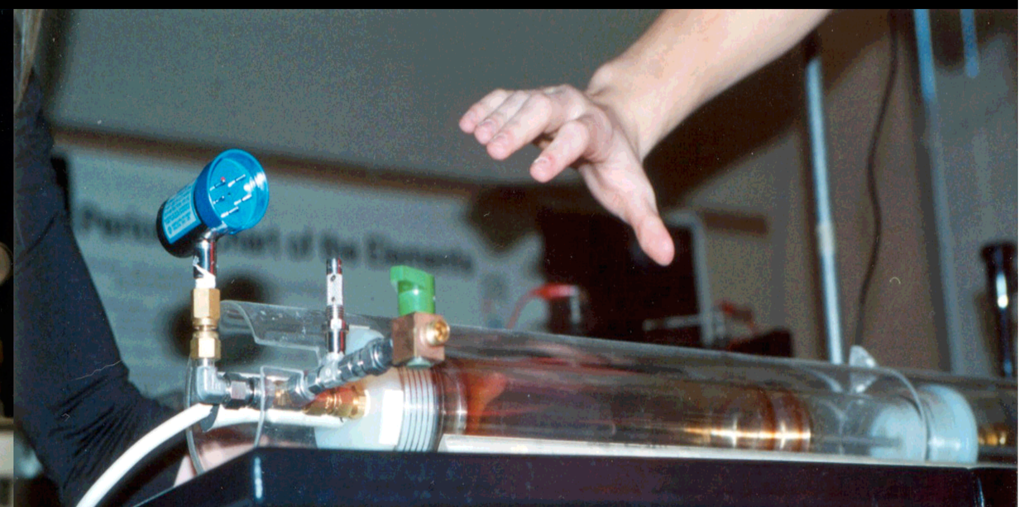
T_i and T_e

• Electromagnetism



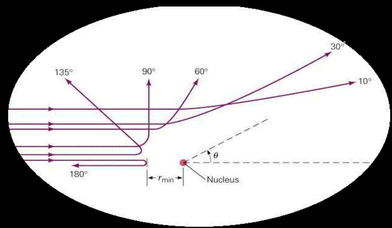
Right Hand – No Doubt!

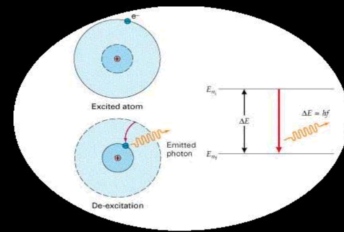


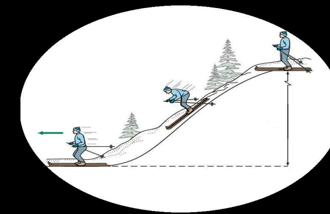


Ions or Electrons? Hmm...

•Conservation of Momentum •Atomic and Quantum Physics •Conservation of Energy





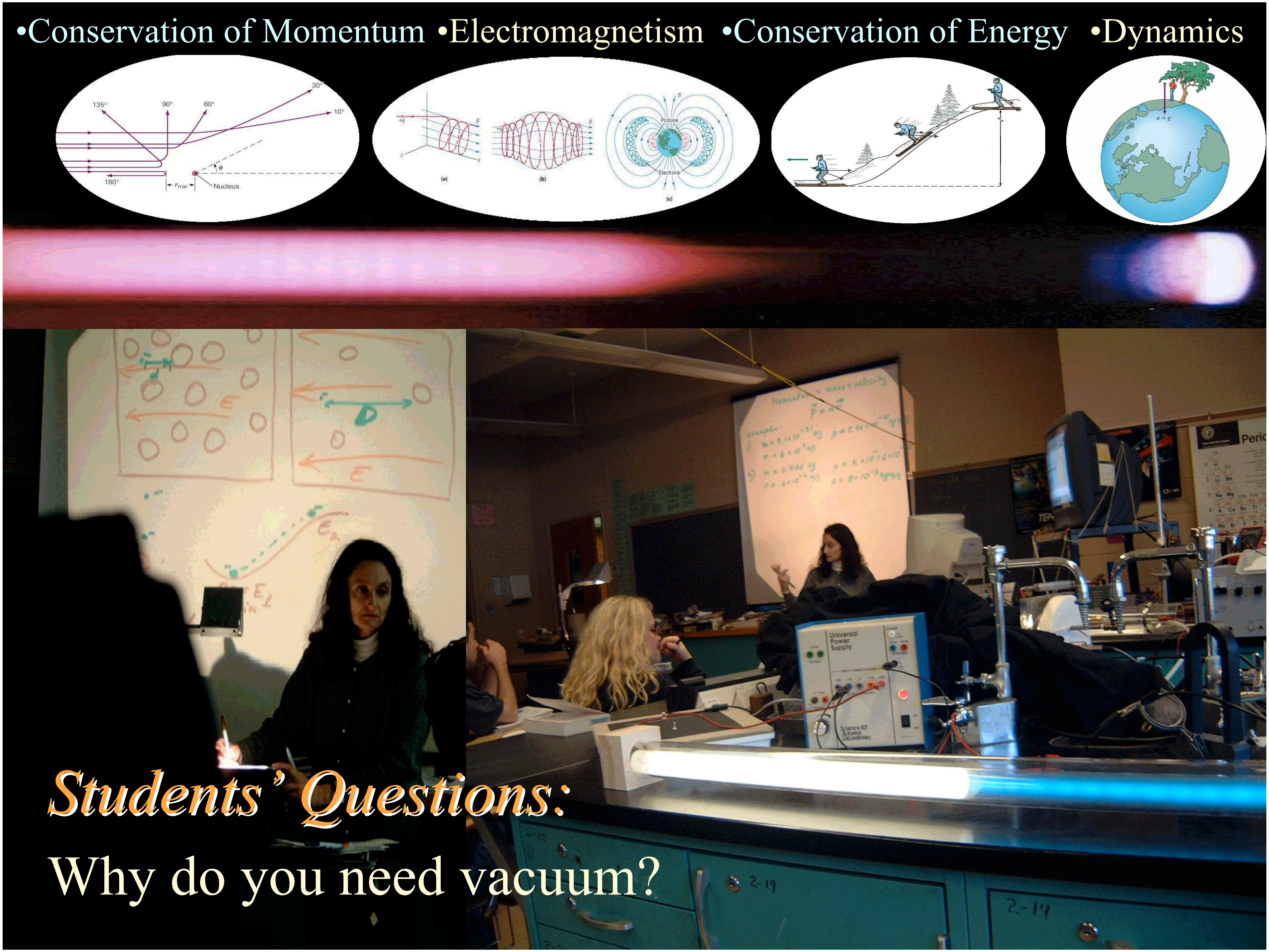


A Glowing Plasma Globe – Set them up then follow their lead [4]

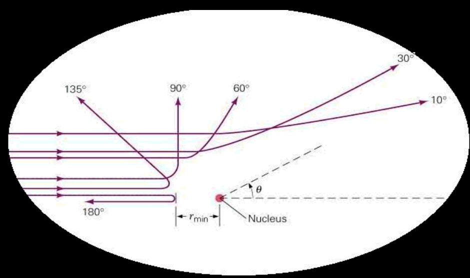
Students' Questions:

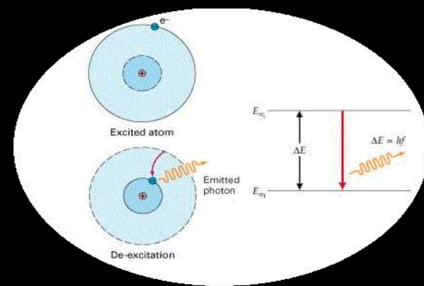
Why does it glow?
What makes it purple?
Why are there strings of light?
Why does it only glow inside?

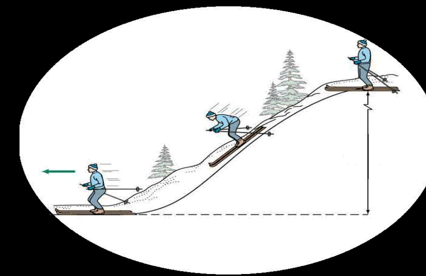
4. R.R. Hake, "Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses," *Am. J. Phys.* **66** , 64-74 (1998).


•Conservation of Momentum •Electromagnetism •Conservation of Energy •Dynamics
135°
90°
60°
30°
10°
180°
r_{min}
Nucleus
Protons
Electrons
(a)
(b)
(c)
$a = g$
Universal Power Supply
Students' Questions:
Why do you need vacuum?

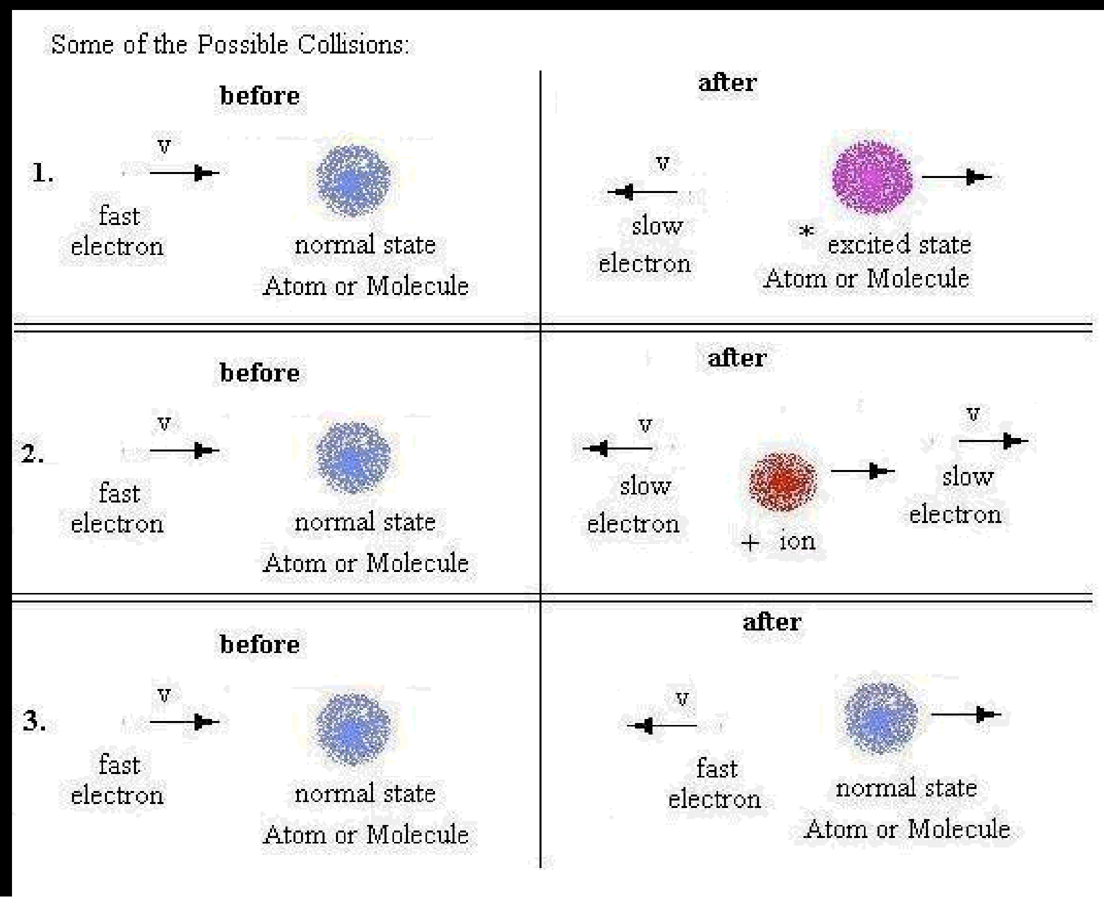
•Conservation of Momentum •Atomic and Quantum Physics •Conservation of Energy







A Glowing Plasma Globe



Elastic and Inelastic Collisions

Using Plasma to Teach Physics: An Example of a Course Curriculum

Watchung Hills Regional High School
108 Stirling Road, Warren NJ 07059
(908)647-4800

Physics J Curriculum Draft
Sophia Gershman
2001

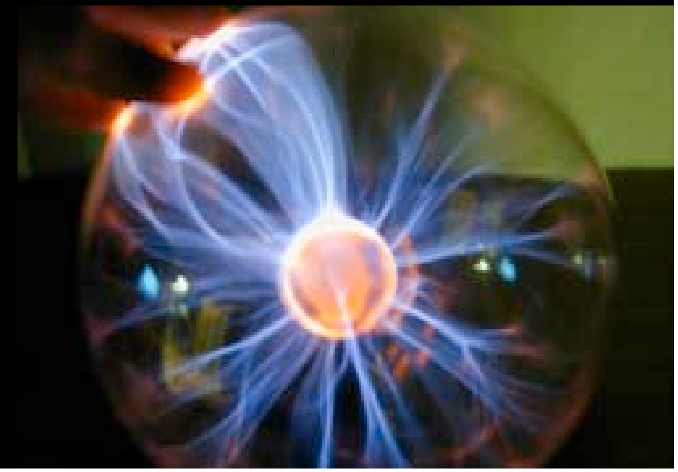


Table of Contents:

Conservation of Energy and Momentum:

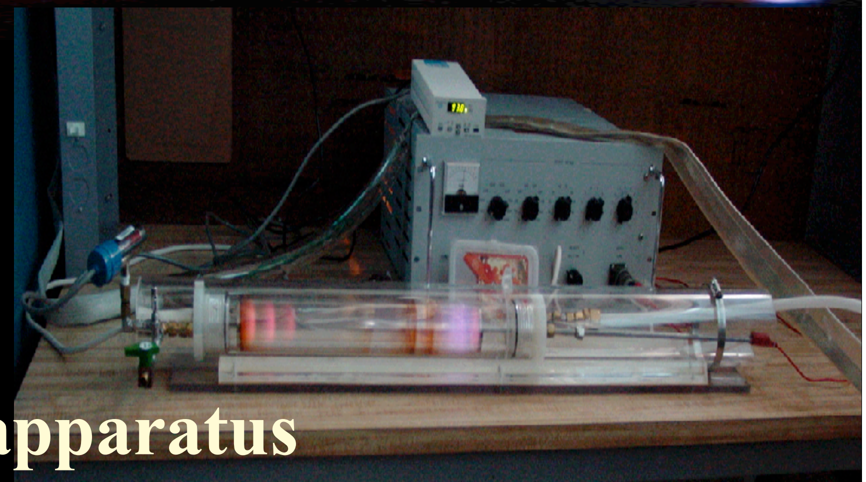
The Students will be able to

133. Identify the energy transformations leading up to the production of electromagnetic radiation in a glow discharge

134. Explain the role of collisions in producing the glow of fluorescent light bulbs, aurora lights, etc

135. Apply conservation of energy to the motion of a single accelerated electron in electric field and to the collisions of electrons with neutral particles in plasma

Experiments:
Simulating a Research Environment [5, 6]



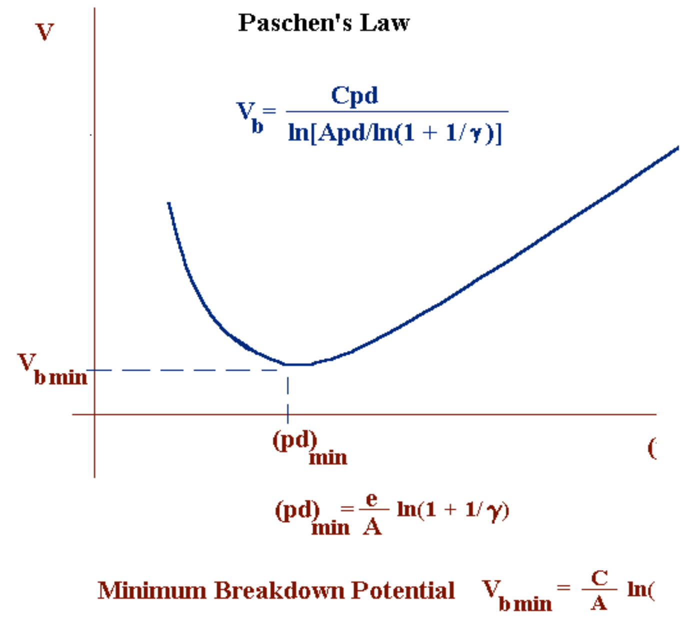
Students

- **Plan all work**
- **Formulate research goals**
- **Request, procure, assemble all apparatus**
- **Collaborate with scientists and engineers**
- **Share their experiences and learn from peer groups**
- **Critique and evaluate each other's work**
- **Write papers and make oral and poster presentations**

5. A. Van Heuvelen, "Learning to think like a physicist: A review of research-based instructional strategies," *Am. J. Phys*. **59**, 891-897 (1991).
6. A. M. Cox, "The Scientist's Apprentice", *Science Teacher,* **65**, 39-41 (1998)

Simulating a Research Environment: Long Term Experiments

- Breakdown in Various Gases



- Microwave Interferometry to Determine Plasma Density

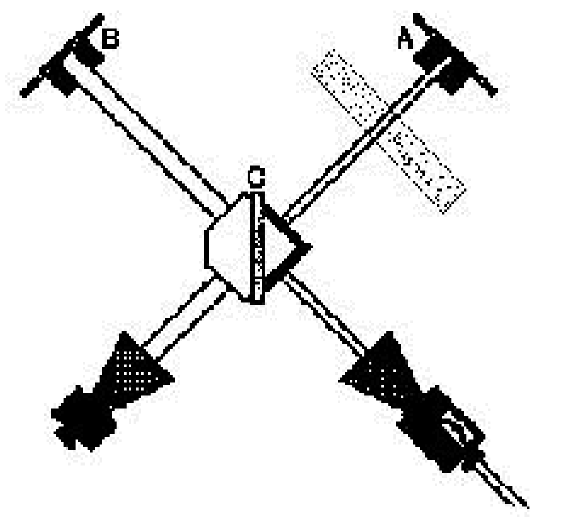
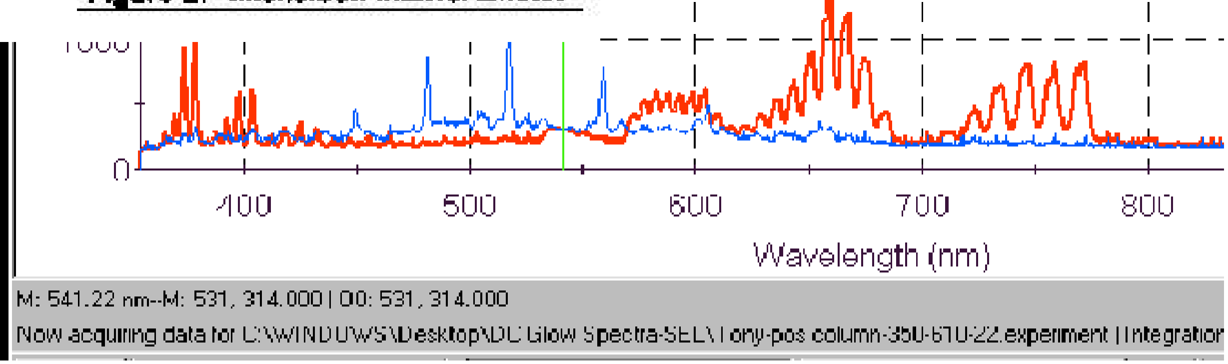


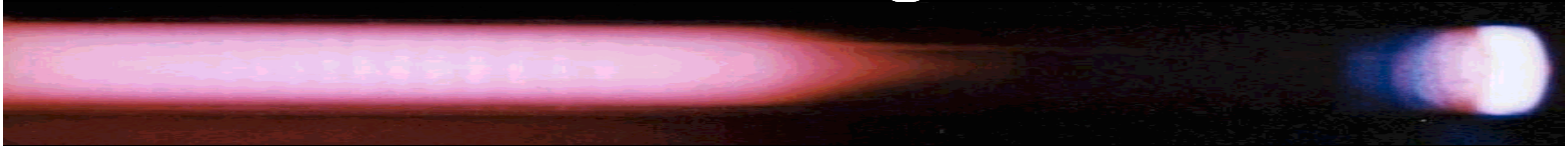
Figure 2. Michelson Interferometer

- Visible Spectrum of Glow Discharge in Various Gasses



- The Study of Ionization Waves Using a Fast Photodiode (under development)

Plasma - Rich Learning Environment



"Besides plasma's obvious merits, it looks cool and is fun to play with, it teaches a type of thinking I think is more important to learn than any single physical concept." A student's comment

Plasmas Unify Introductory Physics

- reduce fragmentation of learning [5, 7]
- encourage active involvement [4]
- construct appropriate mental models [8]

4. R.R. Hake, "Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses," *Am. J. Phys.* **66**, 64-74 (1998).

5. A. Van Heuvelen, "Learning to think like a physicist: A review of research-based instructional strategies," Am. J. Phys. **59**, 891-897 (1991).

7. F. Reif, "Instructional design, cognition, and technology: Applications to the teaching of scientific concepts," J. Res. Sci. Teach. **24**:4, 309-324 (1987).

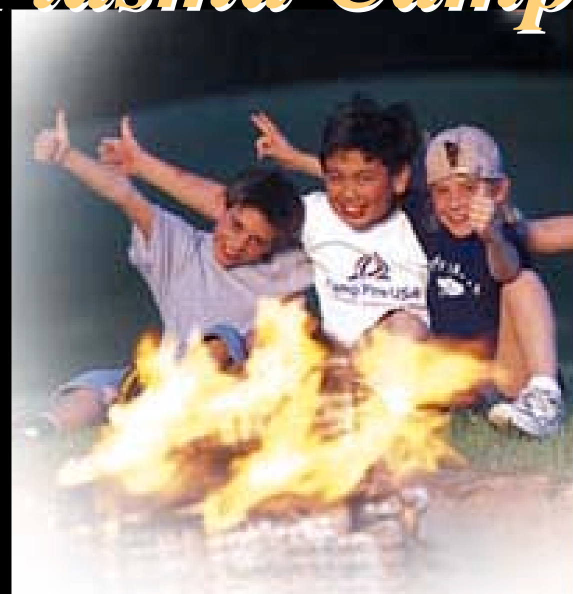
8. E. F. Redish, N. Steinberg, “Teaching Physics: Figuring Out What Works”, Physics Today, 52, 24-30 (1999)

The credits go to:

Plasma Physics and Fusion Energy Institute for High School Physics Teachers

a two-week intensive workshop affectionately known as

Plasma Camp



Andrew Post Zwicker -
Lead Scientist
runs Plasma Camp

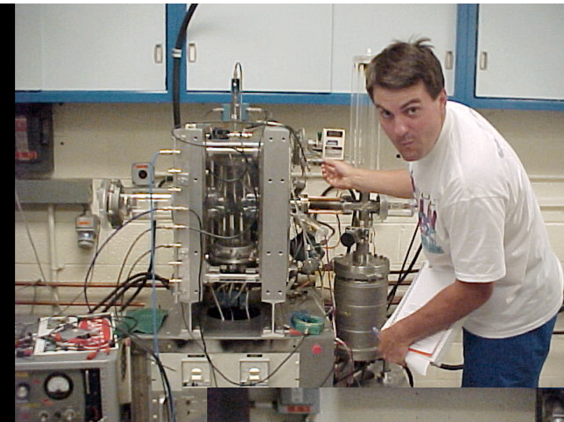
From the workshop overview http://science-education.pppl.gov/SummerInst/ABOUT.HTML

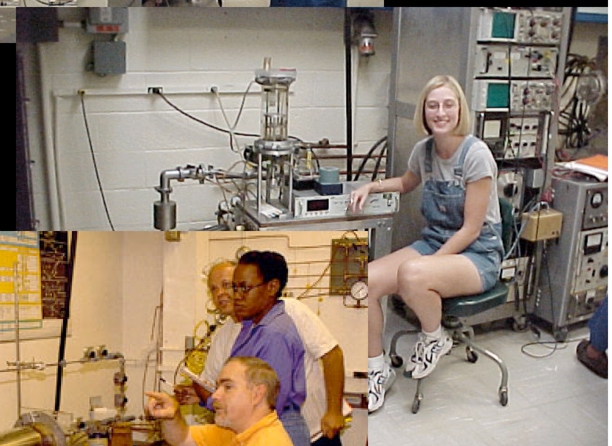
"Plasmas are ideal to illustrate many concepts in … physics curricula including waves, atoms, nuclear reactions, relativity, electricity and magnetism"

Learning by Doing

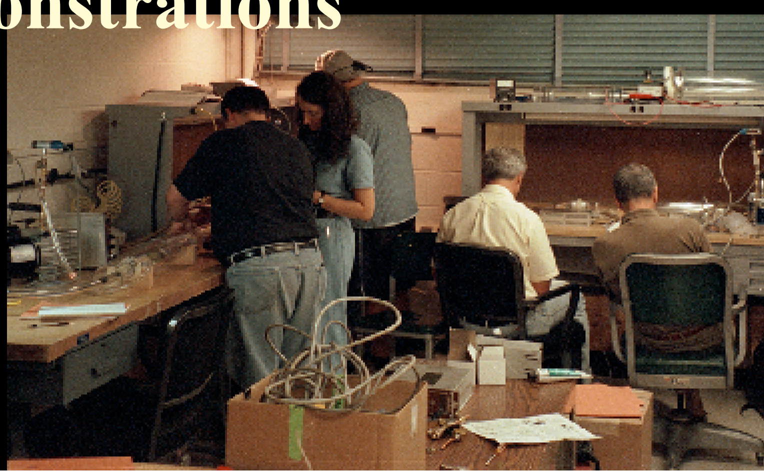
Physics Teachers

- study plasma physics and fusion energy through experimental research
- perform experiments to investigate the basic properties of plasmas
- develop new plasma-based lesson plans, investigations, and demonstrations

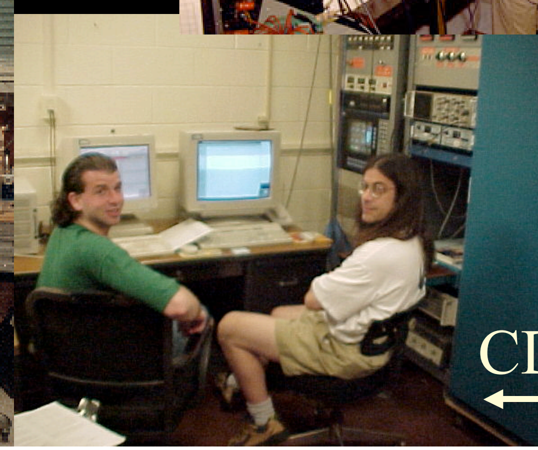




In Dr. Cohen's Graduate Study Laboratory

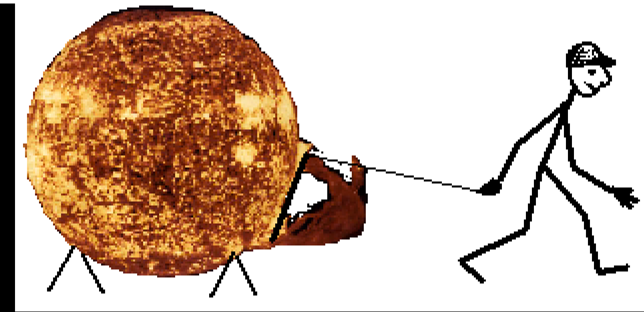


Glow Lab

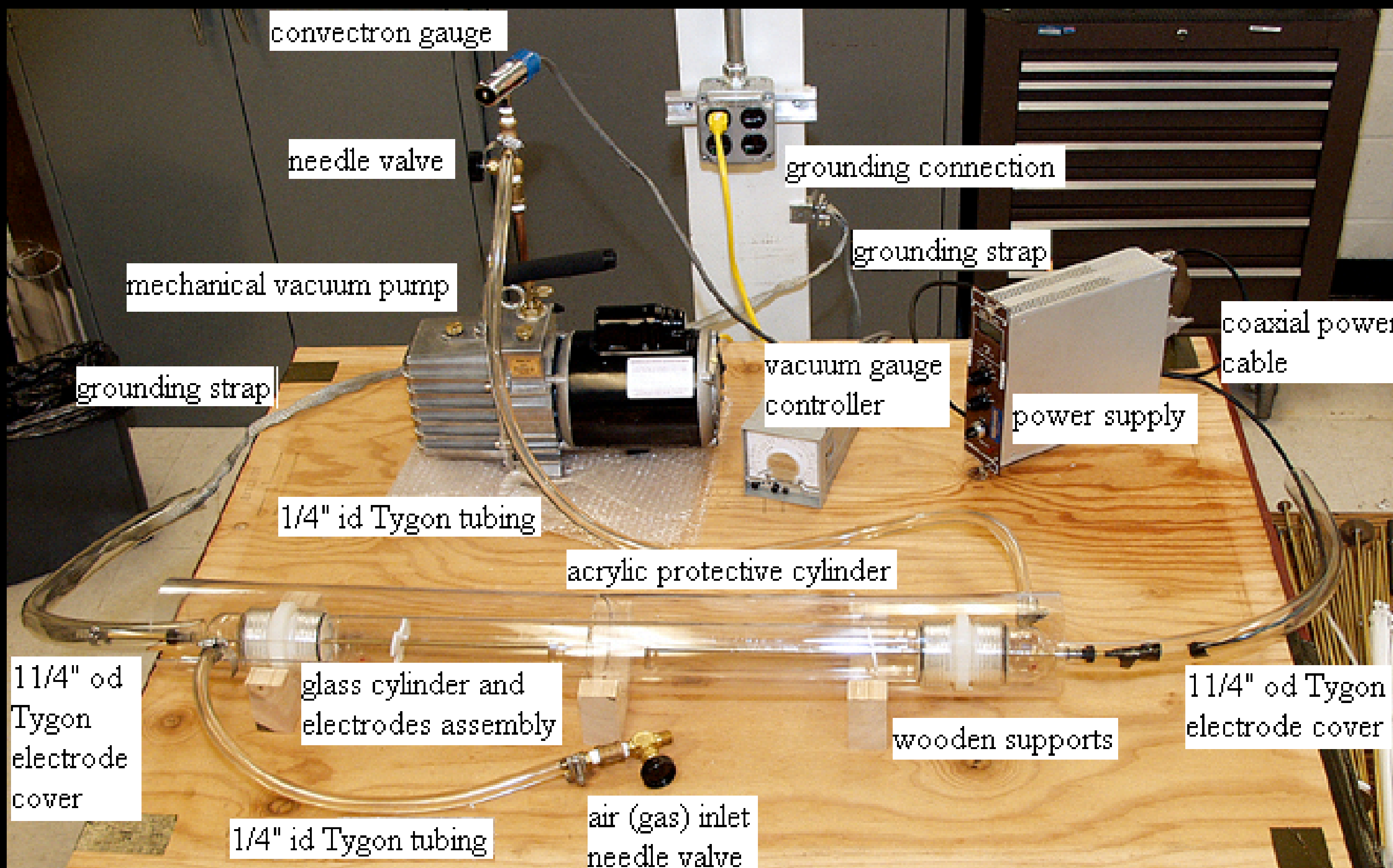


CDX Control room

Your own Pet Plasma:



Want to take it home? –
Here is how:

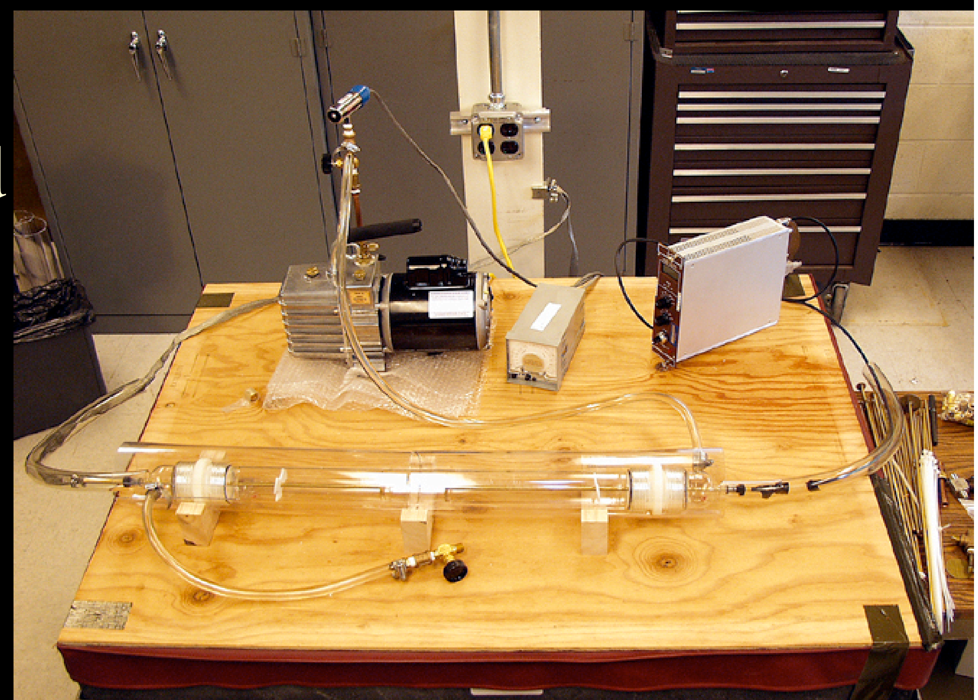


Tools for learning – Tools for teaching

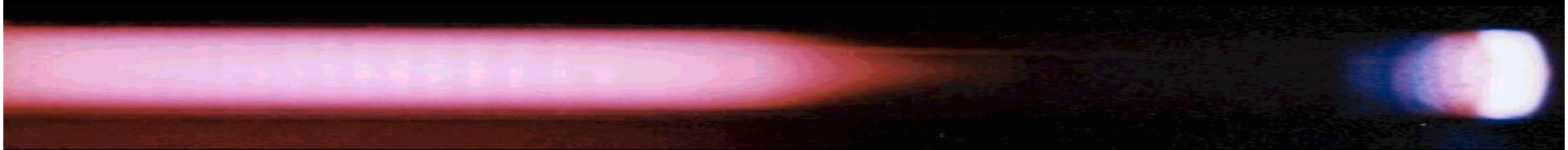
Plasma Camp 2001:

Veteran campers assemble a glow discharge apparatus and experiment with it, learning

- Electrical safety
- Plasma Physics
- Electromagnetism
- Vacuum Techniques
- How to be students



Plasma based Curriculum has been tried



in Various Formats:

- Interactive lecture demonstrations
- Laboratory Experiments
- Research Projects
- “Make and Take” for Teachers

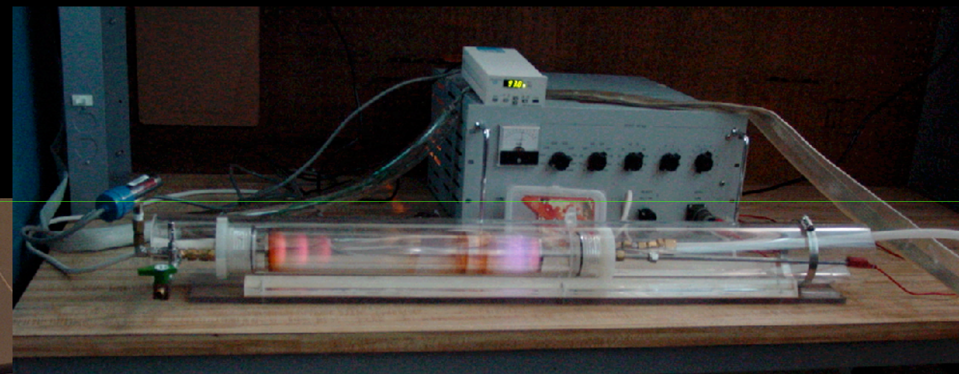
Authors are scientists and teachers, including many Plasma Campers
http://science-education.pppl.gov/SummerInst/CURRICULUM.HTML

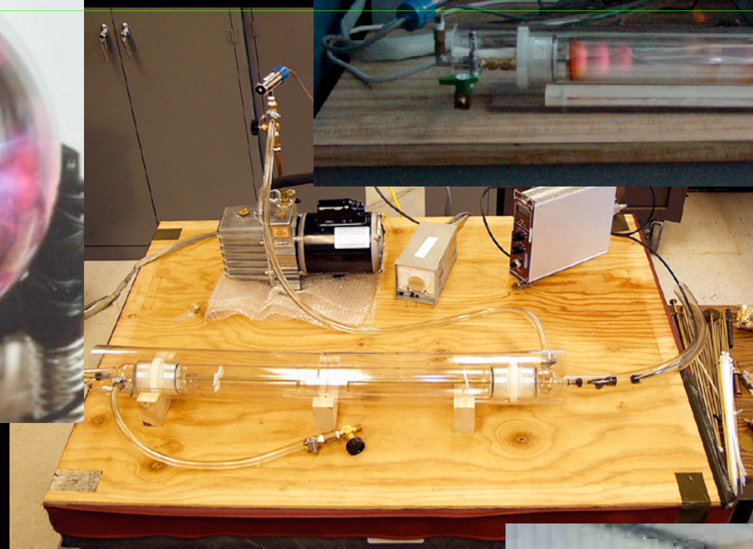
on Various Levels:

- Introductory high school level, algebra based
- Advanced Placement course for high school students, calculus based
- Analytical Physics for Freshmen engineering students, calculus based
- Workshop for Physics Teachers, math levels varied

ALL YOU NEED IS

A few of these





and

a few of those

YOU

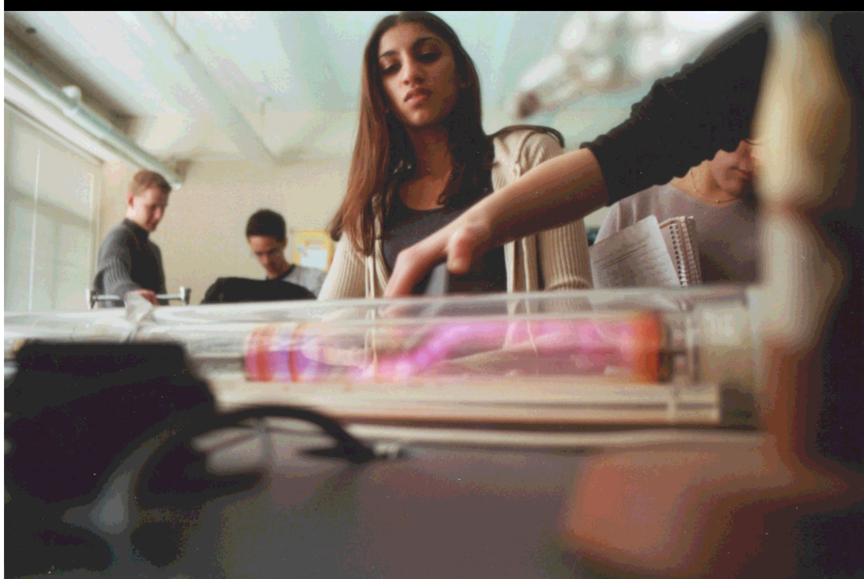
CAN DO IT!

AFTER ALL – IT'S **PLASMA!**

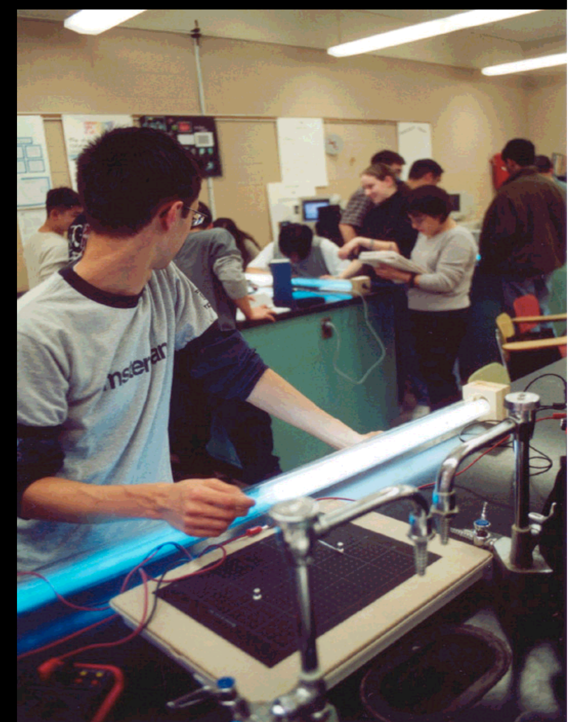
We CAN Share Our Passion with our Students

Embark on true scientific exploration:

DO PLASMA PHYSICS



DO IT ALL THE TIME !



- Increase Scientific Literacy
- Teach Learning and Teaching
- Motivate