Energy Experiments: Getting Started

The first series of experiments will deal with energy. Energy plays the central role in the workings of our environment and it is the source of many of our environmental problems. An understanding of the basic principles of energy – conservation, measurement, conversion and transfer - is essential if you plan to understand environmental problems from a scientific perspective. We will cover these topics in lectures, but the experiments below will allow you to develop in-depth view of these basic principles.

You will spend 2 to 3 lab periods on each experiment you do (2 different experiments in each of the units of the course for a total of 6 during the term). For each lab you will begin with the 'Getting Started' guide. Once you have successfully carried out these fairly explicit experiments, use the rest of the time available to make more explorations on your own: you could look more deeply into what you have done, for example changing the rate of heating or input power to an experiment to see how everything else changes, or testing for errors (energy losses…) in the experiment and then improving the apparatus, or making more quantitative measurements, working with an application of the experiment or going deeper into the physics behind it, or considering the 'scale' of the experiment compared with the 'scale' of the phenomenon in the natural environment. Part of the 'exploration' phase of the experiments involves writing notes in your lab-book on some of the other experiments, and where relevant, relating them to the experiments you have done. Both the 'getting started' phase and the 'later exploration' phase are important to carry out.

We will hand out notes later on with a more detailed background for the experiments but for now we want you to pick an experiment and get started.

List Of Energy Experiments

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E1: SUNS AND RAINBOWS: Examining the solar spectrum.

This lab experiment explores the sun's radiation, which is the primary energy source for most things on Earth. Sunlight is one kind of electromagnetic radiation, distinguished mostly by being visible. Other kinds of invisible radiation are radio waves, x-rays, and infra-red heat. While they seem so different, they are distinguished by their *wavelength* (more on waves, wavelength and frequency is in the extended notes coming later, but for now just think of a wave on water, with peaks and troughs: the wavelength is the distance between two peaks).

Visible light falls in the range of wavelength between 400 and 700 nanometers, or 0.4 to 0.7 micrometers (microns), or 0.4 to 0.7 x 10^{-6} meters. Our eyes and ocular nerves sense the wavelength, and that is what we call 'color': across the colors of the rainbow from red-orange-yellow-green-blue-violet the wavelengths go from longer to shorter (red light has about 650 nanometer wavelength and blue light about 450 nanometer wavelength). Here we want to look at both the wavelengths (colors) that make up light and also its intensity and the rate of energy flow (the 'power') in a light beam.

A. GETTING STARTED

1. Examine the hand-held spectrometer, which breaks light into its component colors. **Do not point it directly at the sun!** First look at the fluorescent lights and flashlights in the lab (**not lasers**) and record what you see.

2. Look at outdoor light (**not sunlight directly**) and record what you see

3. There is a relationship between the color of light radiated from a hot object, and its temperature. Look at a candle flame, and perhaps a Bunsen burner flame. The highest temperatures are in the lower part of the flame, with lower temperatures above (at some height the burning flame ends where amount of burnable gas is not enough to support combustion). Record what colors you see where. The result from studies in physics is that the radiated power varies like the 4^{th} power of the temperature, T^4 in degrees Kelvin, or just 'Kelvins' (that's temperature in degrees Celsius plus 273. (Zero Kelvin is 'absolute zero', the point at which molecules cease to move and no radiation occurs; the dark sky at night is about 3 degrees above absolute zero (3K) temperature of the Universe). Light with wavelength greater than 'red' is called 'infrared'. We can't see it but we can feel it: it is heat, waves carrying heat. Take a silvery dish or piece of aluminum foil, which reflects waves very well (it's a mirror!) and place it close to your face. See if you can feel the reflected heat waves that are constantly being radiated from your face. Measure your skin temperature at the same time. Although we can't see heat waves, some cameras can, allowing imaging of warm objects at night.

4. Consult with the E2 group (Lenses and Mirrors) to learn about the bending of light beams when they pass through transparent materials, and how this can split white sunlight into its component colors. The idea is to use a laser beam which has just one color (red, here) as a sample 'sunbeam' or 'ray' and then to think of white light as the sum of many such rays with differing wavelengths (colors). (the low-power red (632 nanometer wavelength) laser is rated below 1 milliWatt of power which is less than a laser pointer or supermarket scanner. This laser is operated by switching on the power supply. The voltage should read about 12 volts.)

5. Our lab engineer, Eric Lindahl, has salvaged a spectrograph. Look at some of the printouts from this instrument and then ask him to show you how it works.

E2. LENSES AND MIRRORS: Concentrating energy and taking apart sunlight, ray by ray

Read the introduction to E1, which is a closely related experiment. For several reasons it is good to understand rays of light and how they are changed when they move from one medium (like a vacuum) to another like air or glass or water. The experiments are basic 'optics' but with an environmental flavor.

A. GETTING STARTED

1. You have some lenses, mirrors, prisms and a light source. The light source is a low-power laser. We emphasize that it is very important to be sure that any laser you work with, without laser safety glasses, is not powerful enough to be dangerous. (Even common laser pointers put out up to 5 milliwatts, apparently can damage your eye if shown directly into it. Here we have less than 1 milliwatt of laser power which we are assured is safe. See the lab safety sheet that has been handed out.) It is always good to avoid getting the beam straight in your eye!

The small 'fish-tank' acts as a test chamber. To see the light beams generate some carbon dioxide 'mist' using dry ice. The dry ice can be placed in a small beaker with some water, sitting in an elevated position above the floor of the tank (**do not touch the dry ice with your bare hands - it is about -60° C!**) In absence of dry ice put about 10 cm of water in the tank to visualize the light beams. Pass the light beam into the fish-tank and set up the prism, observing the bending of light as it passes through. Look fairly carefully at this light-bending process, the way it varies with the direction of the beam. Show that for some directions, the light beam can't enter the prism at all.

2. Now try the same experiment with the glass lens. A lens is just like a series of prisms with different angles. Trace out the bending of the red beam as it enters different parts of the lens. Find the 'focus' or point which the beams all pass through, for different angles. Show that if the light source is placed near the focus of a lens the rays emerge from it parallel to one another (exiting rays all have the same angle, regardless of incoming angle). This is a reciprocal or 'reversible' relationship: light from a great distance arrives as parallel rays, which come together at the focus which we reverse by placing a light source at the focus of the lens. What determines the power of a lens (a lens with a small focal length is 'powerful').

3. Try the same experiment with a mirror. Note the relationship of the angles of the incoming and outgoing rays (that is, the incident and reflected rays). Take the curved mirror and show that it too has a 'focus', and think about the relation of the focal length (the distance from mirror to the focus) and the amount the mirror is curved. There is a pair of mirrors connected together with a 'hinge'. Shine the laser beam at these, seeing how the reflected rays depend on the corner angle between the mirrors.

4. It happens that the angle of refraction for a prism depends on the wavelength (color) of the light. This is described in the introduction to E1. Look at skylight (not the sun directly) with the prism and record in detail what you see. This is the process of breaking white light into its many component colors. Communicate with the E1 team to learn more about this process.

5. Experiment with images seen through the small lens and those projected on a piece of paper: why do distant objects appear upsidedown when the lens is far from your eye, yet rightsideup at other distances? This lens and the lenses in your eyes combine in such experiments. Which is more powerful?

E3 A MODEL RIVER: Energy conversion in a propeller-driven water channel

The water channel, or 'flume', in the lab is not like any river in Nature, but is a model with which to think about real rivers. A very common problem in the energy world is the generation of electricity. Why not generate heat and transmit it to where it is needed? It happens that transmitting electricity, as alternating currents with very high voltage, can be done with relatively little energy loss (compared with sending a pipeline of hot water across the country which would not be efficient). Electricity is one of the main elements in our energy profile. We have a 'race-track' shaped water channel in which are mounted some small propellers. These propellers are driven by small electric motors, connected to a power supply that provides a controllable voltage and current. If this were a river we could let the moving water spin the propellers, which would turn the coils of wire in the motors; in turn electricity would be generated as the coils of wire passed the magnets fixed near them (*an electric motor can be turned into an electricity generator, running the energy conversion backward).* This describes hydropower, which is a major and economical source of electricity in the Northwest.

This is an experiment about transforming energy from one form to another: electrical to mechanical energy. You will measure how much of the one is required to generate some of the other, and think about why the two are not equal.

A. GETTING STARTED

1. Become familiar with the propellers and power supply that drive the water channel. (When switching on the power supply it is best to turn down the voltage and current knobs all the way counterclockwise so as not to burn out the motors. Then turn up the current knob all the way, and finally, slowly turn up the voltage: hopefully the propellers will start turning. A good setting is about 12 volts. Never exceed 18 Volts). Note the set-up, with water moving freely round the channel. Start the propellers and observe the water velocity increase from zero to some steady value. Now switch off and let the water come back to rest. What is your impression about the time it takes for each stage? Try measuring the velocity at the surface of the water by timing the movement of floating pieces of paper. Is the flow steady or are there whirly motions as well as the average round-and-round flow?

2. Learn how to run the computer and velocity measurement probe (the miniature propeller mounted near the computer). When this is familiar, start the propellers with the water at rest,

and record the velocity against time. Use this plot to estimate the kinetic energy in the water as a function of time. We will provide more details of the formulas in the background document: kinetic energy, KE, = ½ m v^2. where m is the mass of water, and v its velocity. The density of water is roughly 1000 kg per cubic meter (kg m^{-3}).

3. Then estimate the ratio of kinetic energy, say when the water has reached roughly ½ of its final velocity, over the time taken to reach that velocity. This the rate of change of kinetic energy (in Joules) with respect to time, which is a 'power' (in watts, or Joules per second). Calculate the power being put into the flow, using the formula: electrical power P = I V, where I is the current in amperes and V the voltage in volts. Compare the input power with the resulting kinetic energy. Think about reasons that would make the two numbers differ.

4. Once the channel is moving at constant speed, start the velocity measurement and switch off the power. The energy of the flow dies away due to friction within the water and at the edges of the channel. Again plot energy versus time. The loss of energy every second is the power loss in watts. It goes into heat (rubbing of one bit of water on another) and if we were very clever we could measure the warming of the water as this happens. The forces at work during this part of the experiment tell us why the flow reaches a maximum velocity when driven by propellers, and doesn't go any faster.

E4 A HEAT ENGINE: An engine using heated air to make mechanical energy

Energy conversion from one form to another is the essence of an 'engine', whether in a car or electric device. Many such engines turn heat into mechanical energy (which a car does once the chemical energy of gasoline has been converted to heat). In environmental studies we are sensitive to the damage that so many millions of gasoline engines are doing to the atmosphere, and we can see in our lab a promise…in the hydrogen fuel cell…for a much cleaner future. It is worth understanding some of the principles of a basic small engine run by heat, because they will also apply to a much bigger heat engine: the atmosphere/ocean circulation.

A key part of the story is the idea of mechanical work producing a change in energy: formally work is the product of a force exerted on a body times the distance traveled by the body. Just as

force = mass x rate of change of velocity, (Newton's 2d law, f = ma)
force x distance = change of kinetic energy
(kinetic energy being ½ mass x $(\text{velocity})^2$).

and since rate of change of distance = velocity,

force x velocity = mass x rate of change of kinetic energy

Here rate of change of energy (energy in Joules) is an expression of power (in watts or Joules per second).

In these experiments we will see, again and again, the important idea of 'efficiency', waste energy, high-quality and low-quality energy.

A. GETTING STARTED

1. First we want to see how heat energy is put into a gas when it is compressed. This is a basic production of thermal energy by 'work' done, or force times distance as you exert to squeeze the gas. Take the glass bulb with the blue rubber bulb attached and squeeze the bulb. Attach the pressure gauge using the rubber tube coming from the glass bulb, and see what the pressure increase is when you squeeze. The gauge reads in pounds per square inch which you should convert to modern units, Newtons per square meter (or Pascals). Only the change in pressure matters (atmospheric pressure is about 14.7 pounds per sq. inch, or 10^5 Pascals for comparison). Check for leaks (if you hold the blue bulb in a tight squeeze, does the pressure stay high or drift downward?). In later discussion we will show how the force you exert to squeeze the air is a source of energy (both mechanical and thermal). Does the change in pressure agree with what you might expect from the change in volume of the air?

2. The mass of the air inside the apparatus does not change as you compress it, yet it may change temperature. Insert the sensing element of an electric thermometer inside the glass bulb, sealing it as best you can so as not to leak air. Squeeze the bulb and record the temperature change. Warmer air has thermal energy (per unit mass) that varies directly with temperature. Ideally, when you release the pressure, the temperature should go back to where it was…does it?

3. The Stirling engine converts heat into mechanical energy (the heat coming from chemical energy of the fuel). It is not used much in practice even though it can be very efficient. But it makes an ideal test-model for energy conversion and production of kinetic energy which can do 'work'. A small candle heats air in the glass tube, which expands. This alone can do 'work', but we need to make it continually do so, not just once. If the glass tube is heated, the air expands, and then the tube is removed from the heat, the air will cool and contract. In between we extract some energy by allowing the air to do 'work'. Rather than carry out this cycle by hand, we make an apparatus clever enough to do it by itself. It is rather complex, but see if you can first of all get the engine to run and second, figure out how it works. You can control the strength of heating (where you place the candle), and also add or subtract weights (metal washers) so the tube is nearly balanced (allowing it to flip-flop). Finally, the pressure tube is used to adjust the 'springiness' of the flip-flop motion. What is the role of the metal ball inside the tube and the design of the rubber air tube? In the end, it seems that the engine is really an 'oscillator' in which the glass tube can rock back and forth, and the heat source drives the oscillation which represents the creation of mechanical energy from heat.

E5 MY CANDLE BURNS AT BOTH END: Measuring the useful energy content of fuels (energy conversion, hydrocarbon to heat)

Sunshine creates plant life, and there is an energy flow that accompanies the chemistry of photosynthesis. Once the energy is stored in chemical bonds within the plants, some of it remains even as the plant decays. Solar energy becomes entombed as fossil fuel: oil, coal, and gas. The energy released by burning a few common fuels is

hydrogen	142 kJ/g
methane	55
octane	48
methanol	23
paraffin $C_{20}H_{42}$	42

Here the units of energy content are kilojoules (thousands of joules), kJ, per gram of fuel (or alternatively megajoules per kilogram of fuel). Burning a candle produces heat. As it burns, the candle loses weight. By heating some water at the same time we can estimate how much energy is converted by burning the candle. Heated water is a nice 'energy standard' that you should become familiar with.

Experimentally it is found that supplying 4.185 Joules of heat energy to 1 gram of water will raise its temperature by 1 K (1 degree Kelvin or Celsius), if the water is near 150 C. This number 4.185 J/g/K (Joules per gram per degree K), equivalent to 4185 J/kg/K, is called C_p, the specific heat capacity of water (at constant pressure). We can use the water-heating experiment to measure the energy in sunlight or candle wax or oil (and we should even be able to do that frustrating experiment of violently stirring our coffee, and measuring the warm-up).

A. GETTING STARTED

A direct way to explore the energy contained in a fuel is to burn it, and measure the heat produced. Because most burning is incomplete (the smokier it is, the more unburnt stuff is left), there will be some unspent energy in the exhaust. Catalytic converters on wood stoves and cars convert some more of this chemical energy and clean the exhaust in the process.

1. We have a very sensitive scale that measures weights up to 160 grams (0.16 kg). Try to be gentle with it! Readings can be taken to show differences of 0.01 mg (10^{-5} kg), much less than the weight of a fly. (This number is the 'precision' of the measurement. The 'accuracy' of the measurement describes not only the smallest differences measurable but the correctness of the total value, the actual weight). Using a small candle, likely one with a metal shell, measure the rate at which the burning candle becomes lighter.

2. Weigh a soda can full of water and rig it up so that it is suspended just above the candle to catch the heat. Measure and record the temperature of the water versus time.

3. Use this data to calculate the energy content of candle wax (in Joules per kg, J kg^{-1}). Compare this with values found by a Web search. If they disagree, consider what the sources of error in the experiment might be and try to minimize them.

E6. DOES HEAT FLOW UPHILL: Conduction and convection in solids and fluids.

All of our uses of energy involve *conversion* from one form to another, *transport* or '*transmission*' from one place to another, *storage* until we need it, and *conversion* again (perhaps to push you car along). Here we want to explore transport or transmission of heat energy in a fluid and compare it to a solid. The results apply to many flowing systems, as we shall see when we reach the Air & Water part of the course. We want to see energy transport working in both natural (out-door) and man-made energy cycles.

In a solid heat is transferred by *conduction*, a very much slower process, which is direct transfer of vibrations from one molecule to the next. Conduction is clear when something 'feels' hot to the touch. In a liquid or gas heat is transferred by both conduction (collisions of individual molecules) and by net motions of the fluid, a process known as *convection*. Convective energy flow is all around us. The hot-water in our faucets comes from a convectively heated tank (gas or electric input) and the cumulus clouds in the sky are often from air convecting up from the Earth's surface. (*Radiation* is the third form of movement of heat: solar energy is transmitted through space to Earth in the form of light or electromagnetic radiation and this is considered in experiments E1 and E2).

When heat energy is transferred to a fluid, the fluid reacts differently in terms of absorbing and spreading that heat within itself, depending on which direction the heat is coming from. In this experiment you will compare heating a fluid and solid from below and heating them from above, and begin to assess the differences in energy transport, and why they occur.

A. GETTING STARTED

1. Your experimental apparatus comprises two items, an aluminum rod and water filled glass tube each of which has an electrical heater coiled around its center. Both can be oriented at a gentle slope by propping up one end on a piece of wood. To run the heater, set both the current and voltage outputs on the power supply to zero (turn to the left), connect the two wires on each heater to the outputs of the power supply, turn the current setting to maximum and then set the voltage to 5 V (never use a voltage that exceeds 10 V).

2. Use the infrared (non-contact) thermometer (the background document for E1 will help you understand how this works) to monitor the temperature along the rods and the water-filled tube. To do this use a marker pen to place regularly spaced marks along the rod and measure the temperature at each mark at regular intervals (say every 5 minutes but you might want to adjust the interval based on your initial results).

3. Make plots of the temperature versus distance along the rod for different times. How do the results for the metal rod and the water filled tube compare? Can you explain any differences?

4. The conductivity, k, of a material expresses its willingness to move heat. For aluminum k is about 205 Watts per meter per Kelvin ($w\ m^{-1}\ K^{-1}$). For water at 20°C, k = 0.563 W/m/K, which is much smaller than the conductivity of aluminum. By definition, k is the ratio of the flow of heat to the temperature gradient. Approximate this as

$$\text{heat flow } F_h = k\ \Delta T/\Delta X$$

Here ΔT is the temperature difference between two points a distance ΔX apart. Notice the units: F_h has units watts per square meter of material ($W\ m^{-2}$); a given temperature difference will drive a certain amount of energy flow (power) through a cross-section of material (and twice as much through a cross section of twice the area). From this calculate the heat flow at different points, F_h in the experiments. Why do the numbers for water differ from one another?

E7 A SOLAR POND: Energy conversion and storage, solar to thermal

Sunshine falling on the Earth heats it: by *conduction*, heat is carried down into the soil. But this conduction is very slow, and the distance the heat travels is only a meter or so in a year. If you live in a cold climate, you bury your water pipes a meter and a half or so deep so they won't freeze in winter. Permafrost in the Arctic is a frozen layer that never thaws out, even in the warm Arctic summer, because that layer 'averages' the air temperature throughout the year, and summer's heat can't reach it.

Let us imagine a way to trap some of the sun's heat so that it can be used to do useful work. Water is a useful medium, because you can move it, and its heat, readily from place to place. But the sun shining on a lake warms a thin layer at the surface and at the same time much of that heat is given back to the air above, in the form of evaporation and clouds. To improve on this, people in the Middle East and Asia build shallow 'solar ponds' in which a layer of very salty water lies at the bottom. Salt adds to the density of the water (as much as about 25% increase in density). When the sun warms this pond, some of its radiation reaches the lower salty layer. It heats this layer, but the layer cannot 'bubble up' to the surface because of its great density. The heat is trapped.

In the lab, trying this out will give an idea about radiative heating, the distance that sunlight penetrates into a fluid, and other forms of heat transfer. You may not be able to reach the very hot temperatures of the real solar ponds (as hot as 99^0 C) but the trapping of deep heat should be visible.

A. Getting Stared

1. The apparatus involves water in two beakers. One beaker will be filled with plain tap water while the other will be filled with a salty solution in which the concentration of salt increases with depth from near zero at the surface to 10% at depth. If you are lucky we will have prepared this ahead of time for the first lab but it not you will have to prepare this yourself. We will teach you how.

2. Heat the water in each beaker using lamps or heating pads. Measure temperature at several depths in both water layers vs. time. You can first use a thermometer but also try the electronic 'CTD' which gives salinity and temperature profiles recording them on the computer.

3. Is heat trapped in the salty layer? If so, how long does it take to warm up.

4. Using food color dyes, observe the fluid motions and measure the depth of the salty layer vs. time.

E8 YOUR NEXT CAR? THE HYDROGEN FUEL CELL: Energy conversion, chemical to electrical and reverse.

'De-carbonizing' our energy sources is an important trend that has been going on for much of the last century. This means changing from carbon-rich fuels like fire-wood to coal then even better to oil and natural gas, which in each case means more energy with less carbon byproduct both in the form of carbon dioxide gas and incompletely burned fuel (carbon monoxide and soot).

The fuel cell offers tremendous hope for clean fuel. Here pure hydrogen is burned with oxygen to make energy. The only pollution byproduct is pure, fresh water. One problem is, where to get the hydrogen? It must be generated somewhere, and this may involve a fossil-fuel burning generator. But the hope is that a *centralized* fossil fuel plant can have some or most of its carbon 'scrubbed' from its smoky exhaust, and will be cleaner than a *decentralized* burning of fossil fuel in every car and truck and lawnmower. Further in the future, clean renewable energies like solar, wind, and hydropower could generate the hydrogen gas.

A. Getting Stared

1. We often look at energy transformations both ways. Here we start 'backwards' with electrolysis by breaking water into gaseous hydrogen and oxygen. ('lysis' means to dissolve or break apart). The input is electricity, which causes two metal electrodes to have positive and negative charges (the *anode* (+) and *cathode* (-)). By dissolving some sodium carbonate in the water, it can conduct electricity better. Hydrogen ions are attracted to the oppositely charged electrode (the cathode) while oxygen migrates toward the anode. If the voltage is high enough, we get a forced reaction:

$$2H_2O \text{ (liquid)} \Rightarrow 2H_2 \text{ (gas)} + O_2 \text{ (gas)}$$

This is a fuel cell in reverse. By attaching a power supply to the two electrodes and slowly turning up the power (start with voltage and current knobs at zero, all the way counterclockwise; turn the current knob all the way clockwise, then slowly advance the voltage knob until you see bubbles.

2. Try capturing the bubbles in a small inverted beaker from the cathode. How can you tell if it is hydrogen? Note that hydrogen is lighter than room air, and hence will rise above it. You may explore more quantitatively how much gas is produced, compared with the current passing through the liquid multiplied by the time.

3. There is also a beaker with two platinum electrodes with which to do the first fuel cell experiment. Using a 'bent' eyedropper collect some hydrogen that you have just made, and transfer it to one of the platinum electrodes. Using a voltmeter connected to the two electrodes see if a voltage difference develops between the two. If it does, you have made a fuel cell, in which hydrogen gas recombines with oxygen (with the help of the platinum, a catalyst) to make water…and electricity.

4. We have a fully operational fuel cell, in which hydrogen drives an electric motor and hence a propeller. The fuel is a 3% solution of methanol…methyl alcohol. Ask for help here, but what you will do is fill the chamber with fuel and simply watch what happens. Measure how much fuel is used to fill the chamber, and calculate how much chemical energy is stored in it. Measure the voltage produced. To find the power output we need also to know either the current or electrical resistance.

E9 THE WORLD'S SIMPLEST ELECTRIC MOTOR: a solar powered motor.

Electric motors are in themselves remarkable devices. They are everywhere, doing tasks small and large. The details involve electromagnetism; for present purposes, the main result of interest is that putting an electrical current through a wire produces a magnetic field. This means that a wire with current flowing in it can be pulled or pushed by an ordinary magnet (or by another wire with current in it). This gives the germ of the idea, to convert electrical energy into mechanical energy. The motor is just the device that organizes the process for us (rather as the Stirling engine in E5 stems from the idea that heating a gas makes it expand and do work against its surroundings; the engine produces an endless cycle of these events, heat going into work and mechanical energy).

A. Getting Started

1. Start with a single bar magnet and explore the direction the compass points as a funtion of position relative to the magnet.

2. Now take two bar magnets in your hand. How does the force between them vary with their orientation. If you release the two magnets how will they configure themselves.

3. Repeat steps 1 and 2 but replace one of the magnets with a coil through which you will pass current. How do the results compare.

4. We will now consider the simple solar cell electric motor. A coil of wire connected to two solar cells acts as one magnets, while a small permanent magnet is the other. The wire coil is mounted on an old cd which can rotate freely. It uses a ball-point pen as a low-friction bearing. A light source shines on the apparatus. When each solar cell 'sees' the light it generates a current, and the resulting magnetic field attracts the wire loop to the permanent magnet (if it is mounted just right). With everything mounted, turn the disk slowly by hand and see if you can feel the force rising once per revolution. Get the motor running? Can you explain how it works?

5. Try some static tests to find out the voltage produced by the solar cell. Can you think of a way to measure the forces produced by a pair of magnets. With help from the instructors, try to think of a way to measure the power generated by the motor.

Demonstration
E10 : BICYCLE POWER: Generating electricity from mechanical energy (which comes from chemical energy)

A fundamental energy conversion from mechanical to electrical energy, sort of the reverse of experiment E3, occurs when you pedal a bicycle connected to a generator, which is essentially the reverse of the normal energetics of an electric motor. One thing this does is to convince us of the concentrated 'high-quality' nature of electrical energy, and of the chemical energy from which it came. Somehow, the mechanical energy in between seems rather low-quality, or at least our perception is that it takes a lot of sweat to light a light-bulb.

A. Getting Started

1. Inspect the bicycle and generator apparatus. There is an unfortunate detail here: a small amount of power is needed to energize the windings on the generator, hence we have a power supply. This does not amount to substantial power, and would not be necessary at all if we were not using an automotive generator. Check the electrical connections to see that the generator is in fact connected to the light bulbs. Try pedaling and see what happens.

2. Switch from a normal 100 watt bulb to a high-efficiency bulb that puts out about the brightness. Compare the work you have to do.

3. Using a 'multitester' measure the voltage and current flowing in the experiment.

4. We want to know how much physical work you are doing, which could be measured using the force x velocity of your feet on the pedals. We instead measure the force further down the line, at the generator. Try to do this using a balance and the 'torque arm' provided. Does this give the kinds of forces you would expect? What could be the source of inaccuracy?