CNS Institute for Physics Teachers

Title:	**Energy Conversion in a Light Bulb**
Version:	November 2007
Authors:	Zipi Greenwald, Marty Alderman and Julie Nucci
Appropriate Level:	Regents physics
Abstract:	One of the most fundamental principles of physics is the law of conservation of energy. Regardless of its form, energy can not be created or destroyed. It can, however, be converted from one form to another. In this lab, electrical energy is converted to light and internal energy (heat), and light is converted into heat. This experiment, which is based upon http://teacher.pas.rochester.edu/phy_labs/Heat/Heat.html) will examine the specific energy conversions mentioned above.
Time Required:	Two 40 minute lab periods
NY Standards Met:	4.1 Energy exists in many forms, and when these forms change energy is conserved.. 4.1a. All energy transfers are governed by the law of conservation of energy. 4.1b. Energy may be converted among mechanical, electromagnetic, nuclear, and thermal forms. 4.1i Power is the time-rate at which work is done or energy is expended. 4.1j Energy may be stored in electronic or magnetic fields. This energy may be transferred through conductors or space and may be converted to other forms of energy. 4.1n A circuit is a closed path in which a current can exist. 4.1o Circuit components may be connected in series or in parallel. 4.1p Electrical power and energy can be determined for electrical circuits. M1.1 Use algebraic and geometric representations to describe and compare data.

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Objectives:

Upon completion of this lab activity, the student should be able to:

- Write a clear statement of the law of conservation of energy for this system.
- Explain/account for the energy transfers which occur when an incandescent bulb is lit.
- Explain why the clear water does not heat up as much as ink tinted water.
- Wire this simple circuit and understand that a voltmeter is wired in parallel and an ammeter in series.
- Distinguish among UV, visible, and IR electromagnetic energies.
- Explain that heat is energy in the form of infrared radiation.

Class Time Required:

- two 40 minute class periods

Teacher Preparation Time:

- No special preparation required

Assumed Prior Knowledge of Students:

- Students should be comfortable with basic calorimetry (NYS Regents chemistry level or higher).
- Students should have a working knowledge of the conservation of energy in the context of mechanics to apply to this case.
- It is helpful if students should have already covered basic circuits.

Background Information for Teacher:

http://www.olympusmicro.com/primer/anatomy/sources.html

Data

Experiment 1 – Clear Water

V [Volts]	I [Amperes]	P [Watts]= IV	E_e [Joules]=IVΔt
12.30	0.57	7.0	2100

T_i [°C]	**T_f** [°C]	**ΔT** [°C]	**ΔQ_{water}** [J]	**ΔQ_{beaker}** [J]
21	25.4	4.4	1473	188

Experiment 2 – Black Water

T_i [°C]	T_f [°C]	ΔT [°C]	ΔQ_{water} [J]	ΔQ_{beaker} [J]
21.4	26.1	4.7	1633	201

Data Analysis

Experiment #	Water Color	ΔQ_{water} [J]	ΔQ_{beaker} [J]	ΔQ_{total} [J]
1	clear	1473	188	1662
2	black	1633	201	1834

$$\Delta Q_{\text{visible light}} = \Delta Q_{\text{total, black water}} - \Delta Q_{\text{total, clear water}} = 1834-1662 = 172 \text{ J}$$

1. Calculate the percentage of electrical energy that was converted to visible light using the following equation and show your work:

$$\%\_light\_energy = \frac{\Delta Q_{\text{visible light}}}{E_{\text{electrical}}} \cdot 100 = \frac{172J}{2100J} \cdot 100 = 8.2\%$$

Data for the fluorescent bulb

V [Volts]	I [Amperes]	P = VI [Watts]	$E_{electrical} = VI\Delta t$ [Joules]
		6.2	5580 (15 minutes)

Water Color	T_i [°C]	T_f [°C]	ΔT [°C]	ΔQ_{water} [J]	ΔQ_{beaker} [J]	ΔQ_{tot} [J]
clear	21.5	27.0	25.5			3349
black	20.9	27.4	26.5			4039

Light Source	Efficiency
Incandescent bulb	8.2 %
Fluorescent bulb	12.4 %

<u>Answers to Questions</u>:

1. In general, only about 5 – 10% of an incandescent light bulb's energy is converted into light. How does the number you measured compare to this range?

   The data fits within this range.

2. You know that energy is always conserved. Now write the appropriate energy conservation equation to see how much of the energy conversion you measured in this experiment for the incandescent light bulb. Plug in your data and calculate the percentage of the electrical energy conversion accounted for by the data you have taken.

   Does $E_{electical} = E_{visible\ light} + E_{heat}$?

   Does 2100 J= 172J + 1662?
   Does 2100 = 1834?

   1834/2100 = 87.3%, so 13.7% of the energy was not accounted for by this experiment.

3. What are your sources of error in this experiment? Where did the energy not accounted for in question 2 go? List at least four sources of error.
   1. Heat lost from the beaker to the surrounding air, the table underneath the beaker, and the stopper above the beaker.
   2. Some light can escape the beaker and not be absorbed by the black water.
   3. The UV component is absorbed by the glass and converted to heat. Assuming equilibrium (the water temperature = the glass beaker temperature), the UV component is added to the IR component and it can not be separated out in this experiment. This is an admittedly small component, however, based on the incandescent emission spectrum.
   4. The resistivity of the metal leads isn't zero. Therefore the leads have a finite resistance depending upon their geometry.
   5. The inaccuracy of the thermometer leads to errors.

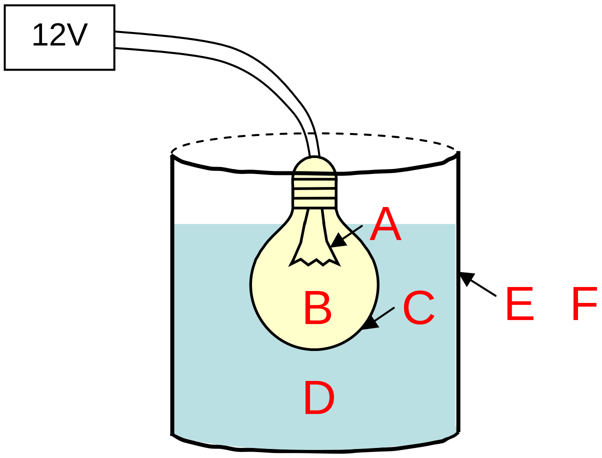
4. What is the efficiency of the incandescent light bulb as a heat source? Show your calculations, neglecting the heat loss that you could not measure in this experiment. Given this result, explain how and why an easy bake oven works.

   $E_{heat}/E_{electrical} = 1662/2100 = 0.79$

   A minimum of 79% of the energy of the bulb is heat.

In an easy bake oven the heat from a simple light bulb is used to bake a cake.

5. By what method does the heat produced by the light bulb transfer between the locations denoted by consecutive letters? List the six heat transfer mechanisms for A → B, B→ C, etc.



A→ B: The heat radiates from the filament into the evacuated bulb at B
B→ C: The radiated heat warms the glass by conduction
C→ D: The heat is transferred from the glass to the water by a combination of conduction and natural convection.
D → E: The heat is transferred from the water to the glass beaker by conduction.
E → F: The heat is transferred from the beaker to the surrounding air by a combination of conduction and natural convection.

6. Why don't you get a sun burn from an incandescent light and why can you get a sun burn from the sun?

You can only get a sun burn from UV radiation. Too little of the emission spectrum in a light bulb comes from the UV to give you a sun burn. The sun has significant UV radiation with high intensity and therefore can burn you.

7. It says in the introduction that you emit electromagnetic radiation. What do you emit (remember that magnetism is another topic not considered here!)? How could you see this radiation?

Infrared or heat energy. One way you can see people in the dark is with night vision googles that see infrared energy. These types of googles are heavily used by the military to locate people at night.

8. Based on this experiment, can you think of ways to lower your parent's electricity bill?

    Besides turn off the lights when you aren't using them, you could also use more efficient light sources, such as fluorescents.

Energy Conversion in a Light Bulb

Material List

Item No.	Quantity	Description
1	1	india ink
2	1	syringe
3	1	1 liter plastic beaker
4	1	an automotive bulb mounted into a ‘drilled-out’ rubber stopper and inserted into a pyrex 100 ml beaker. The rubber stopper has a hole for the thermometer probe. The light bulb is soldered to patch cords with banana clip ends. There are two filaments to choose from in the bulb.
5	2	digital multimeters
6	2	patch cords with banana clip ends
7	1	12 V DC power supply
8	1	digital thermometer

Introduction

You already studied energy conversion in mechanics (PE, KE, $PE_{elastic}$, $E_{internal}$ or heat). This study will examine two non-mechanical examples of energy conversion. First, electrical energy will be converted into light energy (provided by an automotive headlight bulb) and internal energy (heat). Second, the light energy of the first experiment will be largely converted into internal energy, as well. Let's examine the three forms of energy involved in this experiment.

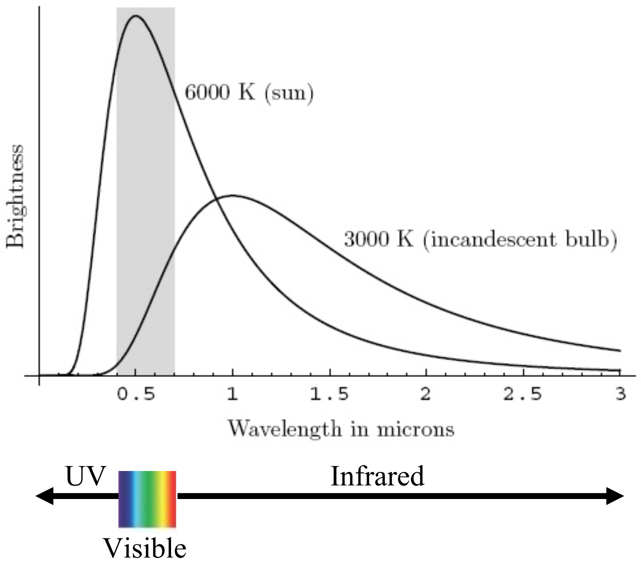
Electrical Energy

Recall from mechanics that energy, measured in Joules, is the ability to do work, and power, measured in Watts, is the *rate* at which work is done. The same is true for electrical energy and power. Anything that utilizes electrical energy is a *load*. The load here will be an automotive light bulb.

Electromagnetic Energy (EM Spectrum)

When electricity flows through the filament of a light bulb, it heats to a very high temperature (~3000°K for Tungsten). This heat excites the electrons, which can then occupy higher energy orbitals. When these excited electrons return to a lower energy orbit they emit a quantum of electromagnetic energy, a photon, with a wavelength corresponding to the energy difference between the two orbits. The electromagnetic energy emitted by a tungsten filament light bulb consists of ultraviolet (UV), visible, and infrared (heat) energies. Compare the incandescent light bulb spectrum to that of the sun in the figure below.

The Electromagnetic Spectrum emitted by the sun and a light bulb



Internal Energy (Thermal Energy or Heat)

Heat transfers throughout our environment all the time. If you jump into an outdoor pool shortly after Memorial Day you are acutely aware of the difference between your body temperature and the water temperature! And you know that on that clear, warm June day you are freezing when standing by the pool wet but pleasantly comfortable if you are dry. Have you ever thought about why that is? Have you ever thought about how you are warmed by the sun?

There are three different mechanisms for heat transfer: conduction, convection, and radiation. Heat is always transferred from a warmer object to a colder one. It is a law of thermodynamics that temperatures equilibrate this way.

Conduction is the transfer of heat between two objects of different temperature that are in direct contact. The pot on the stove is an example. More expensive copper bottom pots have higher conductivity, and therefore heat the food faster and more efficiently. Conduction will also occur within a single object if the temperature within it is not uniform.

Convection is the movement of fluids (gases and liquids) caused by non-uniform temperatures and results in heat transfer. For example, if you put a warm object in cool water, the water in contact with the warm object will warm up, expand as it becomes less dense, and move upwards. Its place is taken by cooler water that will also warm up, expand, and rise. As the warmed water, now away from the object cools, it will sink. This creates convection currents as the water flows around the object. These currents constantly bring cooler water in contact with the warmer object. The reverse is true for a cool object in a warm liquid or gas. This natural convection is how heat is transferred in oceans and semi-fluid materials flow within the earth’s core.

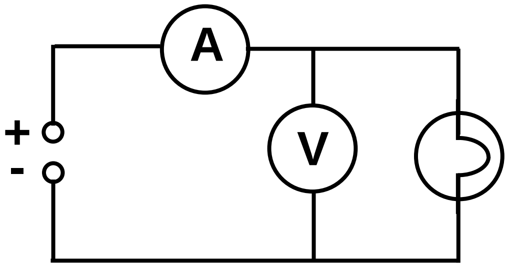
Radiation is the last form of heat transfer. All objects radiate electromagnetic energy (that includes you, too!). The kind of radiation emitted depends on the temperature of the emitting object and the hotter the object the more it emits (it goes as T^4). A hot object likely emits more than it absorbs. A cooler body still emits, but likely absorbs more than it emits. Since electromagnetic radiation travels through empty space (unlike sound!) no physical contact is needed for radiation to occur. The most important radiation source in your life is the sun.

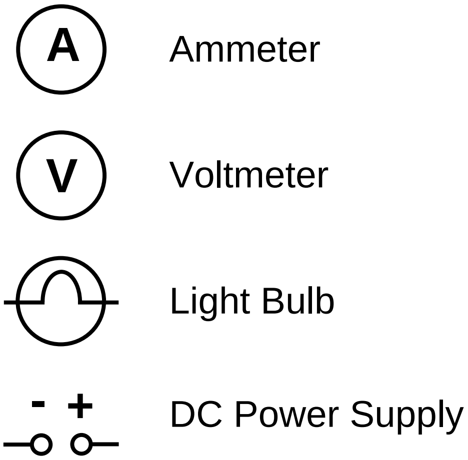
Experimental Section

This lab will test and compare the efficiencies of both fluorescent and incandescent light bulbs. Because testing the fluorescent bulb takes longer, your teacher will run this experiment while you test the incandescent bulb. At the end of the lab you will compare your data for the incandescent bulb with the data for the fluorescent bulb.

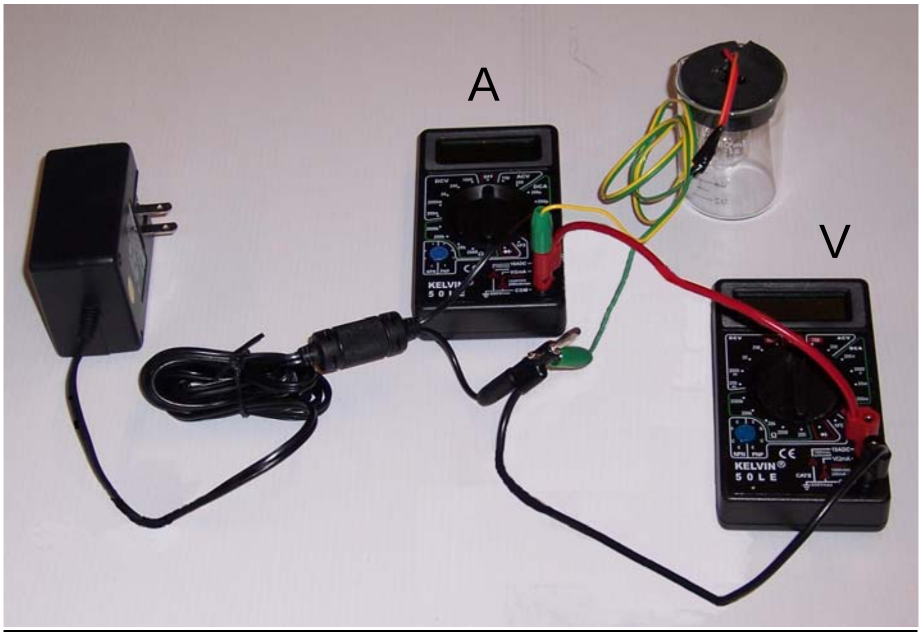
Experiment 1

Here is a schematic of the circuit you will build. These are standard symbols used for drawing circuits. An ammeter is always connected in series and voltmeter is always connected in parallel.





Below is a photograph of the actual circuit to help you wire it together. It is easier to wire the circuit if you first connect the series circuit and then add the voltmeter in parallel.



The electrical energy provided to the light bulb is $\mathbf{E_e}$, and is measured in Joules. It is calculated with the equation: $E_e = P\Delta \mathbf{t}$, where P is electrical power in Watts, and $\Delta \mathbf{t}$ is the time duration of the use of the electricity in seconds. Power is calculated with the equation P=VI, where V is the applied voltage, and I is the current flowing through the load. If **V** is in Volts and **I** is in Amperes, then **P** is in Watts, or Joules per second. Combining the equations provides $\mathbf{E_e = VI\Delta t}$.

Measure the Electrical Energy**:**

1. Insert the rubber holder with the bulb into the empty glass beaker.
2. Wire up the circuit as shown above.
3. Connect to the 10A and com settings on the ammeter.
4. Connect to the DCV 20 and com settings on the voltmeter.
5. Plug in the power supply.
6. *Quickly* measure the current and the voltage and then unplug the power supply to avoid heating up the bulb.
7. Calculate the power and write the answer in the table.
8. Calculate the electrical energy used if the circuit is left on for 5 minutes and enter that value in the table.

V [Volts]	I [Amperes]	P = VI [Watts]	$E_{electrical} = VI\Delta t$ [Joules]

Measure the Internal (Heat) Energy:

1. Fill the 1 liter beaker with water and adjust the water temperature to most closely match room temperature. Stir the water with the probe of the digital thermometer to make sure the water temperature is uniform.
2. Remove the rubber holder/bulb assembly from the beaker.
3. Fill the beaker with 80 ml of water. Measure and record the initial water temperature in the table.
4. Carefully replace the rubber holder/bulb assembly. The bulb will be in the water, but the rubber holder should not get wet.
5. Plug in the power supply for 5 minutes and then unplug it.
6. Carefully remove the rubber holder/bulb assembly from the beaker. Do not splash the water.
7. Stir the water gently with the probe of the digital thermometer for 10-15 seconds. Measure and record the final temperature of the water, T_f, in the table.
8. Dump the water out of the beaker so the beaker returns to room temperature for the next experiment.
9. Calculate and record the temperature change, $\Delta \mathbf{T}$, in the table. Assume that the temperature change of the water is equal to that of the beaker.
10. Calculate and record the internal energy change of the water and the glass beaker using the equation below and add these results to the table.

T_i [°C]	T_f [°C]	ΔT [°C]	ΔQ_{water} [J]	ΔQ_{beaker} [J]

Heat, ΔQ, is energy, and energy is the source or result of work, W. Thus, heat and energy and work all share the same units, Joules. Historically, heat was treated differently and had its own unit, calories. Thompson performed numerous experiments to try to find the relationship between work done and heat generated, and he consistently found that 4.186 joules of mechanical work resulted in one calorie of heat being generated. This constant came to be known as the mechanical equivalent of heat. The heat energy unit 'calorie' is defined as the quantity of heat required to raise one gram of water by 1 Celsius degree.

The formula which describes the change in the internal energy of an object is written:

$$\Delta Q = mc(T_f - T_i) \quad or \quad \Delta Q = mc\Delta T$$

ΔQ = change in internal energy of an object
m = mass of the object
ΔT = change in temperature of the object
c = specific heat capacity of the substance in J/(g °C).
T_f = final temperature
T_i = initial temperature

Substances differ from one another in the quantity of heat needed to produce a given rise of temperature for a given mass. The specific heat capacity, *c*, is a characteristic of the material of the object. In this experiment the heat from the light bulb goes into both the water and the glass beaker. The total heat energy is the sum of these two values.

Values for water
  c = 4.186 J/(g °C)
  m = volume of water in ml (since the density of water = 1 and $1cm^3$=1 ml)

Values for beaker
  c = 0.84 J/(g °C)
  m = 51 grams

Experiment 2

Measure the light energy

In this experiment you will use black ink as a medium to absorb the visible part of the EM spectrum (the light) and thereby convert it into heat. The fact that very little light escapes the black medium is the proof that the visible light is absorbed.

1. Refill the beaker with 80 ml of your room temperature water.
2. Using the supplied syringe to add 3 ml of black ink to the water and mix well.

3. Repeat the measurements from experiment 1 using the blackened water.
4. Using the measured results calculate the increase in the internal energy of the black water, assuming the ink does not change the density of the water. Remember to add the volume of the ink to the water volume.
5. Calculate the heat added to the beaker.

T_i [°C]	T_f [°C]	ΔT [°C]	ΔQ_{water} [J]	ΔQ_{beaker} [J]

Data Analysis for Experiments 1 and 2

1. Calculate the total heat energy produced in both experiments and input the results into the table below.

Experiment #	Water Color	ΔQ_{water} [J]	ΔQ_{beaker} [J]	ΔQ_{total} [J]
1	clear			
2	black			

2. Calculate the electromagnetic energy in the visible light spectrum using the following equation:

$$\Delta Q_{\text{visible light}} = \Delta Q_{\text{total, black water}} - \Delta Q_{\text{total, clear water}}$$

3. Calculate the percentage of electrical energy that was converted to visible light using the following equation. This is a measure of the efficiency of a light bulb as a light source. Show your work:

$$\%\_light\_energy = \frac{\Delta Q_{\text{visible light}}}{E_{\text{electrical}}} \cdot 100 =$$

Comparison with the Fluorescent Bulb

Get the data from your teacher for the fluorescent bulb, fill in the tables, and make the same calculations you made for the incandescent bulb.

V [Volts]	I [Amperes]	$P = VI$ [Watts]	$E_{electrical} = VI\Delta t$ [Joules]

Water Color	**T$_i$** [°C]	**T$_f$** [°C]	**ΔT** [°C]	**ΔQ$_{water}$** [J]	**ΔQ$_{beaker}$** [J]	**ΔQ$_{tot}$** [J]
clear						
black						

Calculate the efficiency of the fluorescent light bulb the same way you calculated it for the incandescent bulb. Show your work. Then enter your final results for both bulbs in the table below.

Light Source	**Efficiency**
Incandescent bulb	
Fluorescent bulb	

Questions

1. In general, only 5 – 10% of an incandescent light bulb's energy is converted into light. How does the number you measured compare to this range?
2. You know that energy is always conserved. Now write the appropriate energy conservation equation to see how much of the energy conversion you measured in this experiment for the incandescent light bulb. Plug in your data and calculate the percentage of the electrical energy conversion accounted for by the data you have taken.
3. What are your sources of error in this experiment? Where did the energy not accounted for in question 2 go? List at least four sources of error.
4. What is the efficiency of the incandescent light bulb as a heat source? Show your calculations, neglecting the heat loss that you could not measure in this experiment. Given this result, explain how and why an easy bake oven works.

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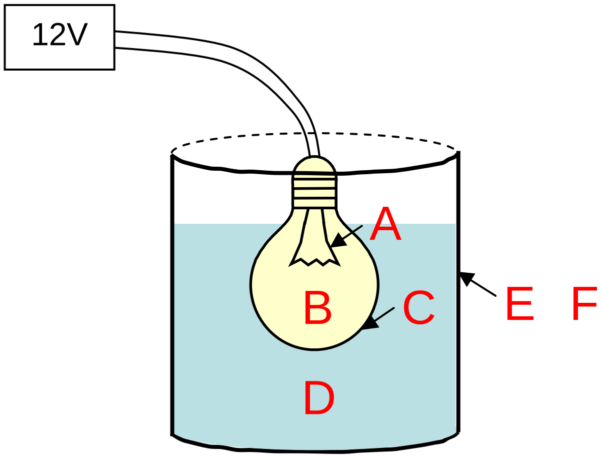

A→ B:
B→ C:
C→ D:
D → E:
E → F:

6. Why don't you get a sun burn from an incandescent light and why can you get a sun burn from the sun?

7. It says in the introduction that you emit electromagnetic radiation. What do you emit (remember that magnetism is another topic not considered here!)? How could you see this radiation?

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