CNS Institute for Physics Teachers

Title:	**Energy Conversion in a Light Bulb**
Version:	November 2007
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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

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

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

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

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

<u>Data for the fluorescent bulb</u>

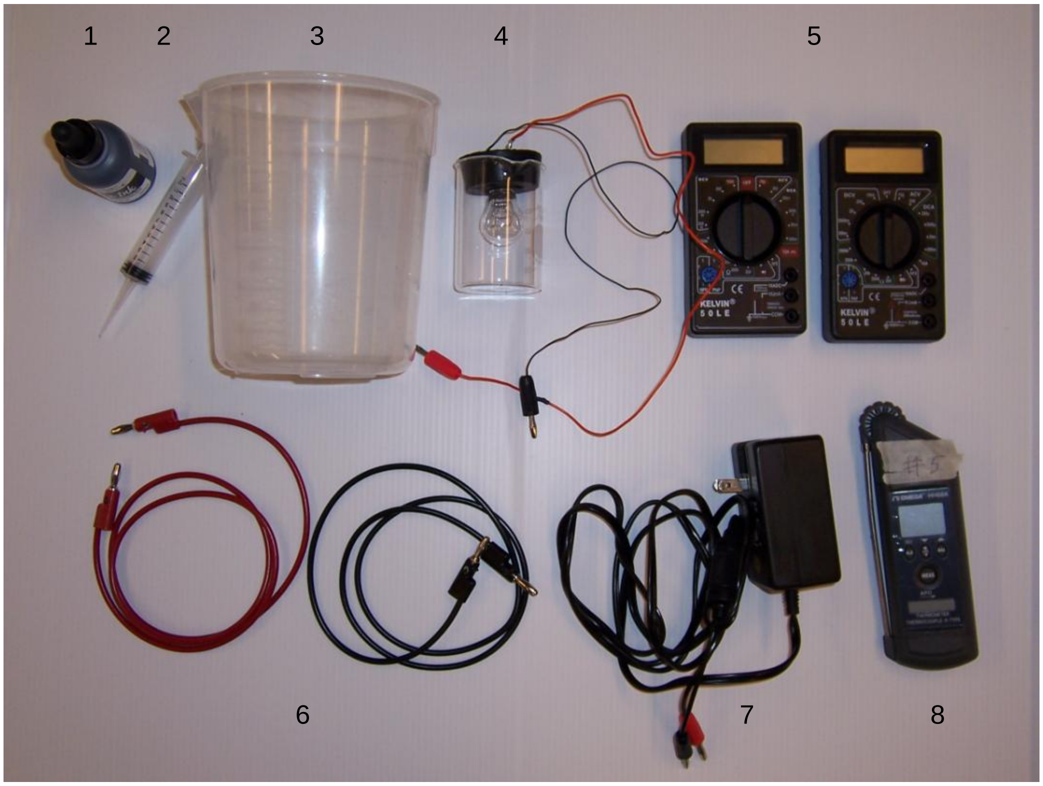
V [Volts]	I [Amperes]	P = VI [Watts]	$E_{electrical} = VI\Delta t$ [Joules]
		6.2	5580 (15 minutes)

Water Color	$\mathbf{T_i}$ [°C]	$\mathbf{T_f}$ [°C]	Δ**T** [°C]	$\Delta \mathbf{Q_{water}}$ [J]	$\Delta \mathbf{Q_{beaker}}$ [J]	$\Delta \mathbf{Q_{tot}}$ [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>: send an email to cipt_contact@cornell.edu to request answers.

Energy Conversion in a Light Bulb



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

ENERGY CONVERSION IN A TUNGSTEN LIGHT BULB
(or why federal legislation will start eliminating them in 2012)

Introduction

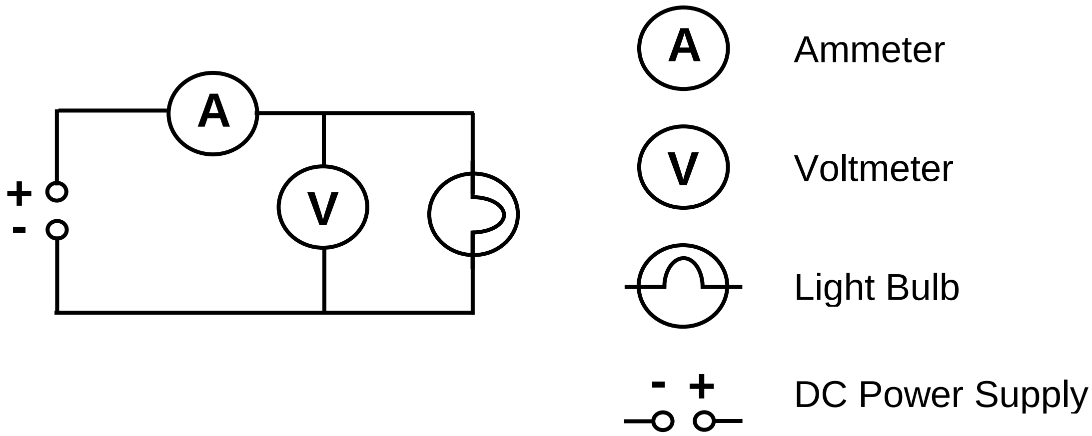
You already studied energy conversion in mechanics (PE, KE, $PE_{elastic}$, $E_{internal}$ or heat). This study will examine two non-mechanical examples of energy conversion. First, electrical energy will be converted into light energy (provided by an automotive headlight bulb) and internal energy (heat). Second, the light energy of the first experiment will also be converted into heat. You will use the data from these two experiments to determine the efficiency of an incandescent light bulb.

Materials

- pyrex beaker
- room temperature water
- two digital multimeters
- two patch cords with banana clip ends
- a 12V DC power supply
- a Vernier temperature probe and LabQuest (or LabPro)
- digital scale
- black ink
- light bulb with black stopper and wires
- stopwatch
- syringe

Experimental Section

Below is a schematic of the circuit you will build. An ammeter is always connected in series and voltmeter is always connected in parallel.



- NOTE: It is easier to wire the circuit if you first connect the series circuit and then add the voltmeter in parallel.

1. Write an equation for the power consumed by the bulb in terms of the variables you can measure with the available equipment (include units).

2. Use your equation from question 1 to write an equation for the electrical energy consumed during an arbitrary time, t. (include units).

<u>Measure the Electrical Energy Consumed by the Light Bulb</u>**:**

- Wire the circuit as shown above.
- Connect to the 10A and com settings on the ammeter.
- Connect to the DCV 20 and com settings on the voltmeter.
- Plug in the power supply.
- *Quickly* measure the current and the voltage and then unplug the power supply to avoid heating up the bulb.
- Use your equation from question 1 to calculate the power and write the answer in the table.
- Use your equation from question 2 to 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 [Watts]	$E_{electrical}$ [Joules]

<u>Measure the Internal (Heat) Energy Produced by the Light Bulb</u>

In this experiment you will measure how much of the electrical energy of the light bulb is converted to internal energy (heat). The formula that describes the change in the internal energy of an object is:

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

ΔQ = change in internal energy (heat) of an object (J)
m = mass of the object (g)
ΔT = change in temperature of the object (°C)
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.

value for water: c = 4.186 J/(g °C)
value for pyrex beaker: c = 0.84 J/(g °C)

3. You need to add 70 ml of water to your beaker. Given the materials provided and what you know about water, what is the most accurate way to do this? Why?

- Weigh the beaker on the digital scale.
- Add 70 ml of water to the beaker using the method you determined to be most accurate.
- Measure and record the initial water temperature in the table.
- Carefully insert the rubber holder/bulb assembly. The bulb will be in the water, but the rubber holder should not get wet.
- Plug in the power supply for 5 minutes and then unplug it.
- Immediately remove the rubber holder/bulb assembly from the beaker.
- Stir the water gently with the probe of the digital thermometer.
- Measure and record the final temperature of the water, T_f, in the table.
- Dump the water out of the beaker so the beaker returns to room temperature for the next experiment.
- Calculate and record the temperature change, Δ**T**, in the table.
- 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.

Data for Clear Water					
$\mathbf{T_i}$ [°C]	$\mathbf{T_f}$ [°C]	Δ**T** [°C]	$\Delta \mathbf{Q_{water}}$ [J]	$\Delta \mathbf{Q_{beaker}}$ [J]	$\Delta \mathbf{Q_{total}}$ [J]

4. What value did you use for Δ**T** for the beaker? How did you get to this number?

5. Write an expression for the total change in the internal energy of this system and add it to the table above:

Measure the Light (Optical) Energy Produced by the Light Bulb:
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.

- Add 67 ml of room temperature water to the beaker.
- Using the supplied syringe to add 3 ml of black ink to the water and mix well.
- Repeat the measurements and calculations from the previous experiment using the blackened water and fill in the table below.

Data for Blackened Water					
$\mathbf{T_i}$ [°C]	$\mathbf{T_f}$ [°C]	Δ**T** [°C]	$\Delta\mathbf{Q}_{\mathbf{water}}$ [J]	$\Delta\mathbf{Q}_{\mathbf{beaker}}$ [J]	$\Delta\mathbf{Q}_{\mathbf{total}}$ [J]

6. Why is or isn’t it a good assumption that all the light energy was converted to heat? Based your answer on your observations.

7. What other assumptions did you make in conducting this experiment?

8. Use this data determine the amount of optical energy emitted by the light bulb. Write out your equation and your answer in Joules.

9. 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:

$$\%\_light\_energy = \frac{\Delta \mathrm{Q}_{\text{visible light}}}{\mathrm{E}_{\text{electrical}}} \cdot 100 =$$

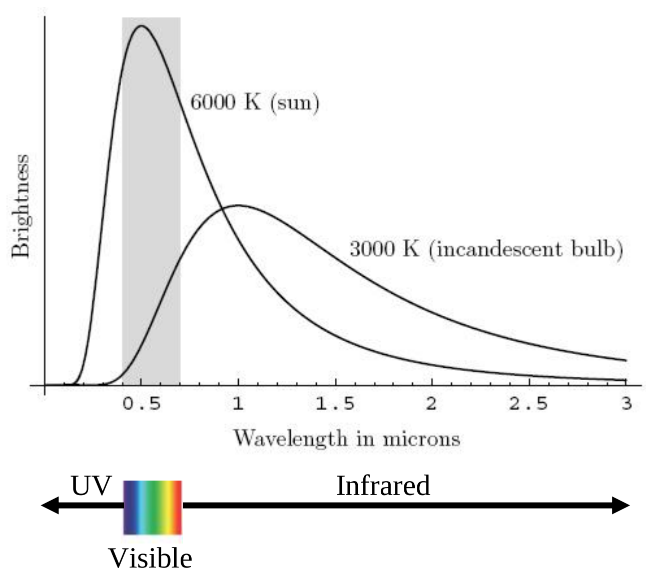
10. You know that energy is always conserved. Write the appropriate energy conservation equation to see how much of the energy conversion you measured in this experiment for the incandescent light bulb. Plug in your data and calculate the percentage of the electrical energy conversion accounted for by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

- Compare your results with other lab groups. Discuss why some groups accounted for more of the total energy than other groups.

11. What are your sources of error in this experiment? Where did the energy not accounted for in question 10 go? List some sources of error.

12. Based upon your data, what is the efficiency of the incandescent light bulb as a heat (*infrared energy*) source? Show your calculations.

13. Use the graph below to determine whether the sun or an incandescent bulb is a more efficient source of light? Justify your answer.



14. Based on this experiment, explain why federal legislation will begin eliminating incandescent light bulbs starting in 2012.

Important Information for Teachers to Share with their Students

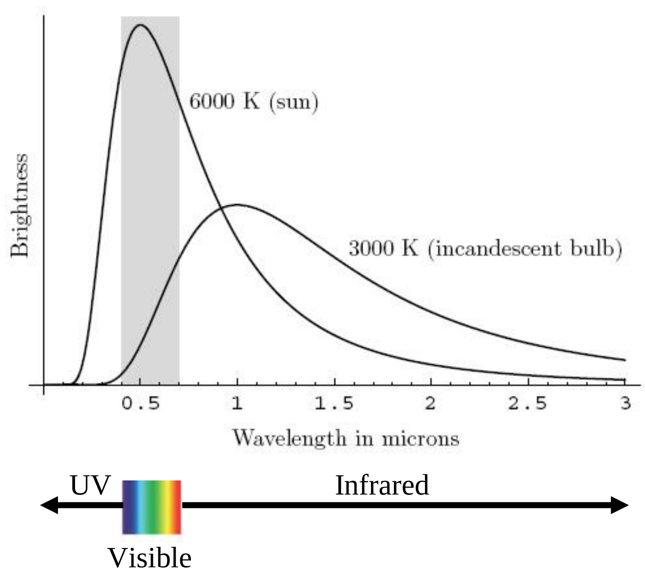
<u>Electrical Energy</u>

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.

<u>Electromagnetic Energy (EM Spectrum)</u>

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 electron states. 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



<u>Internal Energy (Thermal Energy or Heat)</u>

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.

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.