Chapter 28: Electrical Power

Electrical Energy and Power

Now that we have acquired a basic working knowledge of DC circuits, it is time to begin to connect these concepts with all of our previous topics. As usual, the connection comes through the idea of energy.

In a circuit, charges flow from the negative to the positive end of a battery. Since charges are moving across a potential difference, work is done and energy is changing forms. All we need to know is how to evaluate the electrical energy in a circuit and we will be able to connect electricity to all of our other forms of energy.

Before we do so, let us take a minute to remind ourselves of a number of important concepts dealing with energy:

1.) Remember that Work = Energy. To do a certain amount of work, the same amount of energy must be supplied. Work and energy are basically interchangeable.

2.) Recall that power is the rate at which work is done. Power = Work/time (measured in Watts, or Joules/sec)

3.) Since $P=W/t$:

$$\text{Work}=Pt$$
$$\text{Energy}=Pt$$

Thus we can use a power unit times a time unit to be a unit of energy. We often see kW.hrs as a unit of energy. One kilowatt hour is the energy found by multiplying one thousand watts by one hour (in seconds).

4.) The efficiency of a device is given by output/input in terms of energy or power.

In electricity, the power of a device is often given on the device (for example, a 60 W light bulb), but it can also be easily calculated by:

$$P = iV.$$

Which says that the power of a device is equal to the current running through it times the voltage across it. An astute student should be able to derive this equation. Some simple hints would be: recall $W = q\Delta V$ and $P = W/t$. These, along with the definition of current should give it to you (that was more hints than an astute student should need). For a resistor, this can be combined with the pseudo-Ohm's Law to give:

$$P = i^2R.$$

Let us begin by immediately doing some sample problems.

EX D.) How many joules of energy does a light bulb operating on 120 V and 0.5 A use in one day? How much is that in kilowatt hours?

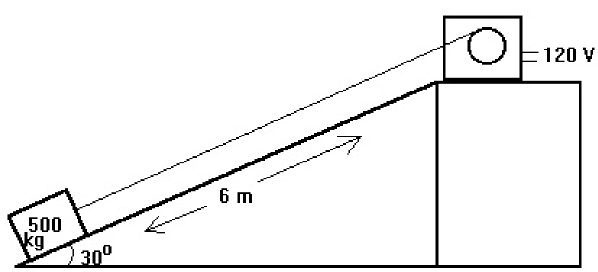
Now we are ready for some more serious problems.

EX K.) A 4 Ω resistor is connected to a 6 V battery and then immersed in a beaker of water (1000 mL) at 20^0 C. What is the temperature of the water 60 minutes later? (assume that the beaker is perfectly insulated and no heat escapes).

The important thing to notice here is how the electrical energy has been changed over to heat energy.

Ex. T.) Assume an electric car (mass = 1500 kg) uses a 100 V battery as its power source. If a current of 4 A runs though the engine, which is 60% efficient, what speed can the car achieve from a dead stop in 30 seconds?

Ex. D.) A motor connected to a 120 V power line is being used to pull a 500 kg box up the incline below. If it is to accomplish the task in 6 sec, what must be the resistance of the motor? (no friction, motor is 10% efficient).



Ex. M.) Two motors, one with an internal resistance of 6 Ω and another with an internal resistance of 4 Ω are wired to a 12 V battery, first in series and then in parallel. In both cases, each of the motors are attached to a 100 g weight and the time it takes them to lift the weight 2 m is found. Which motor wins when they are hooked up parallel? Which wins when they are in series?

Assignment #28

1.) How much does it cost, at 5 cents/kW.hr, to leave a 75 W light bulb on for one week ? What is the current and resistance in the bulb ? (house voltage = 120 V) (ELE10)

2.) If a device does 9000 J of work in 30 seconds and is 70% efficient, what is the resistance of the device if it operates on 120 V?

3.) If a motor that operates on 120 V and carries a current of 3 A is able to do 5000 J of work in 20 seconds, what is its efficiency?

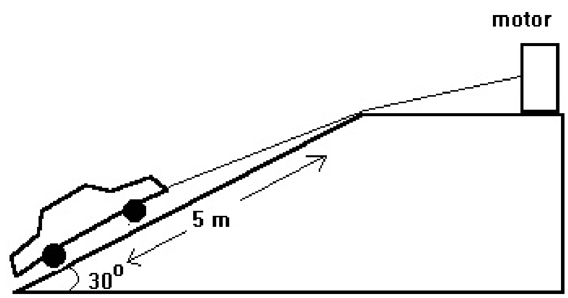
4.) How many electrons pass through a 5 W light bulb connected to a 6V dc cell in one minute?

5.) A conveyor belt attached to a motor is used to lift thingamajigs from a factory floor to a loading dock. If the motor operates on 120 V, has a resistance of 35 Ohms, and is 75% efficient, how many thingamajigs could it lift in one hour? (weight of a thingamajig = 30 N, length of belt = 15 m, angle of belt to floor = $30°$, ignore friction)

6.) Imagine that during a lab, someone left a resistor hooked up to a battery. If the resistor was 5 Ω and the battery was 6 V, how long could it be left hooked up before it reached a temperature of 102^0 C, when it would explode? (specific heat of resistor: 0.4 J/g^0C, mass: 75 g, room temperature: 27^0 C, assume no loss of heat to air)

7.) Imagine that a 60 W light bulb gave off 80% of its energy in the form of heat. How much would the temperature of the room increase in 8 hours if the light was left on? (dimensions of the room: 7 m x 4 m x 3m, density of air: 0.0013 g/cm^3, specific heat of air; 0.01 J/g^0C)

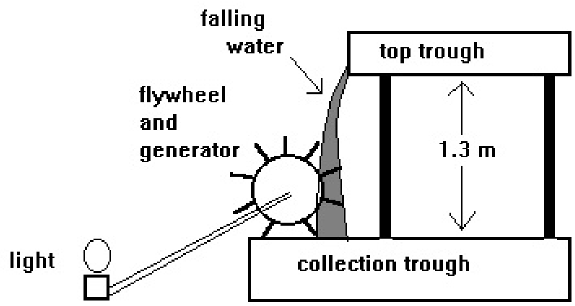
8.) In the set-up below, an electric motor pulls a car up a 30^0 ramp and onto a tow truck. If the car weighs 10,000 N, the ramp is 5 m long, it takes 45 sec to pull the car to the top of the ramp, the motor is operating off a 12 V generator, what is the resistance of the motor? (assume the coefficient of friction on the ramp is 0.02 and the car is pulled up a very slow, constant speed)



9.) Suppose a load of clothes is placed in a dryer. If the clothes contained 3 kg of water and were at 27° C when they were deposited, how long would you have to run the dryer at 240 V and 4 A to evaporated all the water? Make the following assumptions: 40% of the dryers energy goes to heat and the water in the clothes only absorbs 30% of the available heat. Check the reasonableness of your answer and comment on the assumptions.

10.) The reason Tommy's watch is always so fast is that the resistor in it is smaller than what it should be. If the time is directly related to the power output of the watch (i.e. : a 10% fast watch has 10% more power) and Tommy's watch is 7% fast and has a 1.5 V battery and a power output of 0.05 mW, what is the current and the resistor that are a.) presently in his watch and b.) that should be in his watch ? (ELE2)

11.) Consider the strange contraption illustrated below. A 60 W light bulb is hooked up to a generator that is powered by falling water. The water is then taken out of the bottom trough and moved to the top by hand. How many gallons of water would have to be moved to keep the light bulb burning? Assume the wheel and generator are 100% efficient so that all the energy of the falling water is translated directly to electrical energy.



12.) Decipher: "Unawareness of the force of local and national statutory regulations will not enable one to secure understanding and forgiveness in a court of law."

Lab # Electrical Power

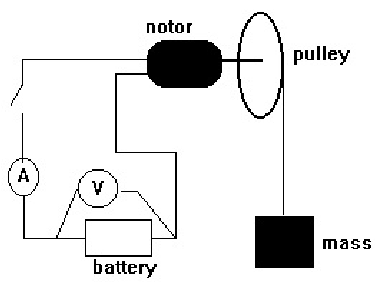
Purpose: In this lab you will set up an electrical motor and connect it to a pulley. You will use this pulley to lift different amounts of mass and time how long it takes to lift each one. From this info, along with the current and voltage readings from the motor, you will determine the efficiency of the system.

Materials: Electric motor, switch, 6 volt batter, wires, pulley or wheel with string attached, masses, meter stick, stop watch, ammeter, voltmeter.

Procedure:

1.) Set up the motor in series with a battery, a switch and an ammeter. Attach the voltmeter in parallel with the motor.

2.) Making sure the string is firmly attached to the pulley, attach it to the rod extending from the motor. Attach a mass hang er to the end of the string.



3.) Turn the motor on and time how long it takes to lift the mass. Also record the height lifted, the voltage, the current and the amount of mass lifted.

4.) Repeat the above procedure using different masses (at least 8 trials).

Trial	Mass	Height	Time	Current	Volts	Power In	Power Out	Eff.
1								
2								
3								
4								
5								
6								
7								
8								

Conclusions: Make a graph of efficiency versus mass lifted. Comment on any patterns you notice.

Activity # - Overloading Circuits

Warning: Goggles should be worn during this activity. There is a very small chance that a battery might explode.

Purpose: The purpose of this activity is to see what happens when a power source (a battery) is overloaded and required to run more devices than it normally might be able to. We will do this by hooking light bulbs up to a battery in series and in parallel. We will measure the voltage across the battery and the current coming out of it. We will then add more and more light bulbs and continue measuring the current and voltage.

Materials: One "D" cell battery, lots of wires, a switch, ammeter, voltmeter, light bulbs.

Procedure:

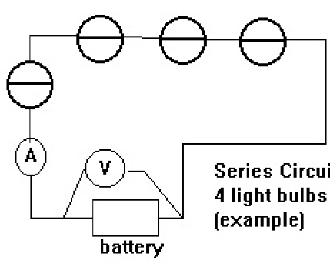
1.) Connect the battery, switch, ammeter and one light bulb in series.

2.) Record the voltage and current for the battery.

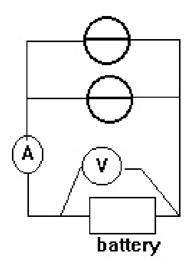
3.) Add another light bulb in series, and repeat the measurements. Continue this until you have 8 light bulbs in series.

4.) Graph power expended by the battery versus number of light bulbs.

5.) Repeat the procedure for light bulbs connected in parallel.



Series Circuit with 4 light bulbs (example)



Parallel Circuit with 2 light bulbs (example)

Series	Circuit		Parallel	Circuit	
# bulbs	Voltage	Current	# bulbs	Voltage	Current

Conclusions: Are any patterns obvious? What does this activity tell us about the power restrictions on a battery?