February 20, 2007
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Student Handout.

Electrical Power & Energy.

Ohms & Power Laws attached.

Force:

- A moving body requires a force applied to it to stop it or change its direction.

Work:

- Work is done whenever a force causes movement or when energy is transformed from one form to another form of energy.

Energy:

- Is defined as the ability to do work, it can be converted to other forms and work is done when energy is changed from one form to another.

Power:

- Is the rate at which energy is transformed?

Electrical Energy

A power station is a place where other forms of energy - coal, gas, potential energy in water and nuclear energy - are turned into electrical energy for transmission to places that use electrical energy.

What Is Electrical Power?

When current passes through a resistor, electrical energy is converted into heat. This heat is DISSIPATED into the surrounding air.

The rate at which this dissipation occurs is called POWER and is measured in WATTS.

Horsepower goes back to the days when horses ruled the world, literally!

The Scottish Engineer and inventor, James Watt (1736-1819), introduced the term "horsepower". The term was and is used to indicate the rate at which an engine can deliver work. As such, it is a measure of power, that is, energy produced or worked done by an engine per unit time. Mr. Watt made considerable improvements to steam engines (which were invented about 70 years earlier, in 1698, by Thomas Savery). His improvements led to engines that were four times more efficient (used less coal) than others, much smaller than before, and much more powerful (from earlier 6 horsepower ones to about 200 horsepower). Oh, you could NOT fit one under the hood, any hood.

Naturally, Mr. Watt wanted to tell how powerful his engines were. So, after some tests (not with engines but with horses) he established that on the average, a horse could haul coal at the rate of 22,000 lb-ft per min. For some reason, unknown to me, he decided the raise this number by 50% to arrive at 33,000 lb-ft per minutes (No, horses those days were not on drugs; steroids were not known at that time, but I am sure Mr. Watt had his own reasons for this increase). So, if an engine can push 33,000 Lb of something one foot in one minute, we say that is a one-horsepower engine. By the way, I believe that deliverable power, also known as brake or shaft power, is the one used in automobile industry in the US, and this indicates the practical ability of the engine, i.e., engine power minus losses due to friction, compression, heat, etc.

Horsepower, as a unit of power, belongs to the English system

The unit for power in the metric system is Watt (W). Named after whom?

So, horsepower (abbreviated as hp) is a measure of power, as is Watt (We come full circle, from Mr. Watt and horses to Horsepower and back to Watt!).

Energy.

Work and heat are two forms of energy. If you rub two pieces of metal together and work at it, they heat up! Or if you take a metal bar and put it end-to end between two heavy objects and heat up the rod by a torch, the rod will expand and push the object apart. These two examples show that work and heat are forms of energy and are convertible to one another. Electricity delivered to our homes is also a form of energy.

Energy per unit time, as mentioned, is power. Units of power in common use are horsepower (hp) for work, Btu/hr for heat, and Watt (W) for electricity. As you expect these units are related. It is due to historical precedent that terms other than W are used. In the metric system, we can express all the above in Watts.

In any case, by referring to table of conversions, you will see that one horsepower is 746 W and 2545 Btu/hr.

To summarize:

Power can be expressed in terms of horsepower, Btu/hr, or Watts. Energy, which is power multiplied by time, is expressed, correspondingly, in lb-ft, BTU, and Joules. In particular, 1 W = 1 Joule per second. I BTU=1055 Joules.

Example:
You turn on a 1000 W (=1 kilowatt) electric heater for one hour. The power of the heater is, of course, 1000 W =1.34 hp = 3412 Btu/hr. The energy used or the heat produced is commonly referred to as one kilowatt hour = 1000 W x 3600 seconds = 3600 kilo Joules = 3412 Btu.

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Power:

The amount of power can be calculated by using one of three methods.

1. Power = V x I watts
2. Power = (V x V)/R watts
3. Power = (I x I) R watts

If we place a 10 ohm resistor across a 20 volt battery then Ohms law says that I = V/R = 20/2 =2 amps will flow.

Using (1)

- Power = 20 x 2 = 40 watts

Using (2)

- Power = (20 x 20)/10 = 400/10 = 40 watts.

Using (3)

- Power = (2 x 2) x10 = 4 x 10 = 40 watts.

Using the three different formulae we still arrive at the same answer.

We know that power is the rate at which energy is used. The amount of energy used is measured in JOULES.

Joules = watts x seconds, --------- therefore watts = joules/seconds.

A 1000-watt fire will dissipate 1000 joules per second. With resistors, the greater the dissipation the hotter it gets, and the larger the resistor needs to be.

The electric meter in your house measures UNITS of electricity. A unit is when you use 1000 watts for one hour. This is called 1 Kilowatt-hour.

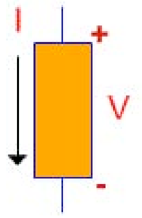
It is kilowatts x hours. A 100-watt (0.1 kilowatts) lamp left on for 24 hours uses 0.1 x 24 = 2.4 units.

You are charged by the unit.

If a unit cost 5 pence then the lamp would cost 12 pence a day to run.

Switch it off and help to save the world.

Electrical power is conceptually simple. Consider a device that has a voltage across it and a current flowing through it. That situation is shown in the diagram.



The voltage across the device is a measure of the energy - in joules - that a unit charge - one coulomb - will dissipate when it flows through the device. If the device is a resistor, then the energy will appear as heat energy in the resistor. If the device is a battery, then the energy will be stored in the battery.

The current is the number of coulombs that flows through the device in one second. Coulomb

Coulomb: *A standard unit of electrical charge. Pronounced "kool-ahm," one coulomb (C) is equivalent to one amp of current flowing through a conductor for one second. It is also equal to 6.25 quintillion electrons (6.25 X 10 to the 18th). From French physicist Charles de Coulomb (1736-1806), who measured the behaviour of electrical charges?*

If each coulomb dissipates V joules, and I coulombs flows in one second, then the rate of energy dissipation is the product, VI.

That's what power is - the rate at which energy is expended.

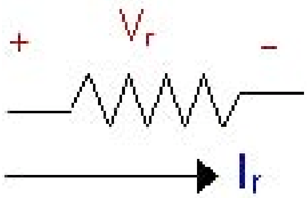
It doesn't matter what the electrical device is, the rate at which energy is delivered to the device is VI as long as the voltage and current are defined as shown.

The power can be negative. If the device is a battery, then current - as defined in the figure - can easily be negative if, for example, a resistor is attached to the battery. If the power is negative, then the rate at which the device expends energy is negative. That really means that it is delivering energy in that situation.

Power in Electrical Devices

A resistor is one device for which you can compute power dissipation.

A symbol for a resistor is shown below, along with a voltage, Vr, across the resistor and a current, Ir, flowing through the resistor.



We can compute the power delivered to the resistor. It's just the product of the voltage across the resistor and the current through the resistor, VrIr.

But there's more to the story.

In a resistor, there is a relationship between the voltage and the current, and we can use that knowledge to get a different expression - one that will give more insight.

- We know that Vr = Rir, so the power is just:
- Power into the resistor = VrIr = (RIr)Ir = R(Ir)2.

- We can also use the expression for the current Ir = Vr/R,
- Power into the resistor = VrIr = Vr(Vr/R) = (Vr)2/R.

At different times, these two results - which are equivalent - can be used - whichever is appropriate. Besides being a useful result these are also illuminating results (And that's not a reference to the fact that a typical light bulb is a resistor that dissipates power/energy.).

The power dissipated by a resistor is always positive. That means that it does not (and in fact it could not) generate energy. It always dissipates energy - uses it up - contributing to the heat death of the universe.

We know the power is positive because R is always positive (and it will always be for any resistor that doesn't have hidden transistors) and because the square of the current has to be a positive number.

Power In Batteries

Batteries are ubiquitous components. They are in TV remotes, cell phones and things like that. But, batteries also appear in places you don't expect them to be. For example, you can turn this computer off. When you turn it back on it remembers things and recalculates things like the time. Now, you expect that for things that can be stored on a hard drive. You don't expect it for the time.

When you turn this computer off and later turn it back on it will have the right date and time. How does it do that? If you think about it (and don't do that for too long!) you have to believe that there is a battery somewhere inside the computer and that when you turn the computer off that battery runs some sort of little clock hidden inside the computer. You can't see the clock and you wouldn't even know it's there, but you can probably see the time now on the task bar of this computer - and it's probably close to being right!

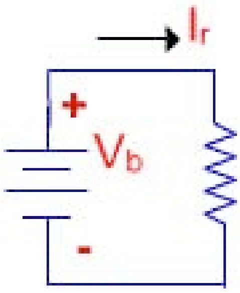
Batteries are used to solve many problems.

They are used to provide power to run things like computer clocks that need to keep running even in the absence of AC power.
They are used to store energy for things like starting a car. When you run the car you generate energy (from the gasoline) and store it in the car battery. Then there is energy there when you need it to get the car going again.
They are used for low power devices to make them portable. That includes things like cell phones, TV remotes and calculators.

You use batteries - whether you want to or not, and whether you know it or not! You need to be able to compute some of the quantities involved. Here is a simple circuit where a resistor is connected to a battery. We know some salient facts about this circuit.

There is energy stored in the battery and the battery delivers stored energy to the resistor.
The resistor dissipates energy, and what happens physically is that the electrical energy that is delivered to the resistor gets turned into heat energy and the resistor becomes warmer.

Now, we need to look at a circuit diagram for this situation. That circuit diagram is shown to the right of the picture below.



In the diagram, we have defined a battery voltage, Vb, and a current, Ir.

Notice that we have used a natural definition for the current polarity. We have the arrow pointing out of the battery and into the resistor. We do that because we know that positive charge actually flows from the battery terminal through the resistor.

That definition of current polarity raises questions about calculation of power to/from the battery. Let us consider the power flow into the battery.

Power flow into the battery or any other device - is the product, VI, when

- V is the voltage across the device, and
- I is the current flowing into the device.

Remember, for our polarity conventions here, the current arrow points into the + terminal of the resistor device. In the battery-resistor circuit, the current arrow is directed out of the positive ("+") terminal of the battery. That means the power delivered to the battery must be computed by (note the minus sign!):

- P = -VI

What does this mean? Let's look at a numerical example. Let's assume the battery voltage is 12 volts and the resistor is 24 ohms. i.e.:

- Ir = 12v/24W = 0.5a

In other words, the power flowing into the battery is:

- P = - Vb Ir = - 12 *0.5 = - 6w

- The power flowing into the battery is negative!
- The power flowing out of the battery is positive!
- And, it makes sense because we know the battery supplies power.

How much energy is stored in a battery?

Batteries are often rated in ampere-hours (or milliampere-hours) and an ampere-hour is really a unit of charge.

As a battery is used it discharges - charge flows from the battery, as time goes on - for the same current drawn from the battery - the voltage stays about the same. There may be a slight drop-off but it is not very large. Thus, if we have a 12.6 v battery, it will have something close to 12.6v until it gets close to being discharged. Let's say we have a 12.6v battery rated at 70 ampere-hours. Assuming it can deliver 1 ampere for 70 hours, then it will be delivering

- Power = 12.6v x 1.0 amp = 12.6 watts for 70 hours.

That works out to 12.6 x 70 = 882 watt-hours or .882 kw-hr. - and remember you pay the electric company by the kilowatt-hour! In joules we have 882 w-hr x 3600sec/hr = 3,175,200 joules.

Other Units of Energy:

British thermal unit - (abbrev. Btu)
A unit of energy equal to 1,055 joules or 252 calories. The amount of energy needed to raise the temperature of one gram of water one degree Celsius. The approximate amount of energy in one match tip.

Calorie (abbrev. cal; pl. calories; also small calorie): 1. A unit of energy often used when measuring the energy content of food. One calorie equals 4.187 joules or 0.003969.

Food calorie (abbrev. Cal, kcal; also Calorie [written with a capital C], Kilocalorie, Large calorie): A unit of energy equal to one kilocalorie. The food calorie is often used when measuring the energy content of food.

Joule - A unit of energy. One joule equals 0.2388 calories or 0.0009481 Btu.

Kilocalorie (abbrev. Cal, kcal; also Calorie [written with a capital C], Food calorie, Large calorie): A unit of energy equal to 1000 calories, 4,187 joules, or 3.969 Btu. The amount of energy needed to raise the temperature of one kilogram of water one degree Celsius.

Kilowatt-hour (abbrev. kWh; pl. Kilowatt-hours): 1. A unit of energy equal to 3,413 Btu or 3,600,000 joules. An amount of energy that results from the steady production or consumption of one kilowatt of power for a period of one hour.

Therm - (pl. Therms) A unit describing the energy contained in natural gas. One therm equals 100,000 Btu. See British Thermal Unit.

Efficiency of electrical appliances:

The efficiency of any device used for converting one form of energy to another is represented by the ration of energy input to energy output.

$$\text{Efficiency} = \frac{\text{Energy output in desired form}}{\text{Energy input}}$$

If we take the example of an electric motor connected to a 250v dc supply, which is developing .5 hp, its efficiency is 85% and we need to calculate the power input to the motor and the current it is drawing from the supply.

.5 hp = 373 watts = 85%

$$\frac{373}{85} * 100 = 439$$

Therefore total power consumed will be 439W

$$I = \frac{P}{E} \text{ therefore } I = 1.756 \text{ amps}$$

Current drawn from the supply is 1.756 amps.

The efficiency of machines and devices that do work is important because of a dwindling supply of energy. This is especially important in the automotive and electrical supply industries because of the reliance on no renewable fuels such as oil gas and coal.

Electrical energy generation via hydro, wind and nuclear sources is most likely the only large-scale supply options for the future generations. Electric and hybrid transport is also set to make its mark felt as the fossil fuel supplies around the world run out.

Student Assessment Questionnaire.

Note: This part of the assessment is open book and 100% is the required result.

1. **If the power rating of an apparatus is 50 watts what will be the energy (Joules) consumed in 2 minutes?**
   - ___________
2. **The energy supplied by an apparatus is its ability to do?**
   - ___________
3. **The three formulas that electrical power can be determined by are?**
   - ___________
   - ___________
   - ___________
4. **_________________ is done when force causes movement!**
5. **Define the relationship between horsepower and watts?**
   - ____
6. **If the power rating of an apparatus is 50 watts what will be the energy (Joules) consumed in 20 days?**
   - ____
7. **What is meant by the power rating of an electrical apparatus?**
   - ____

Name: ________________________________

Course: ________________________________

Date: ________________________________

NSN #: ________________________________

Tutors Signature: ___________________________