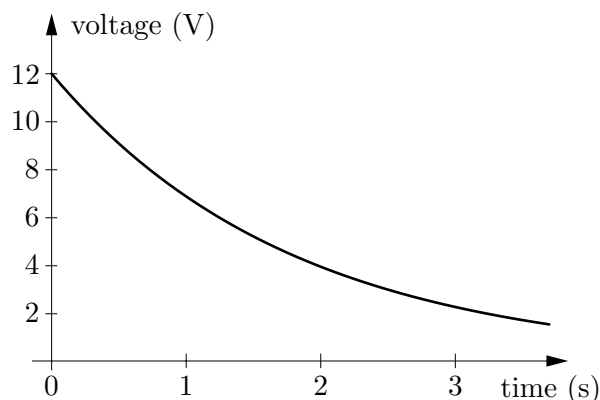
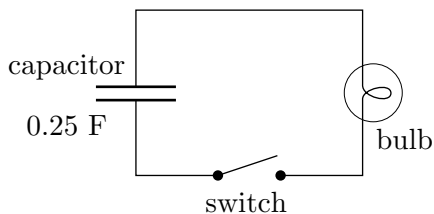


Problem Set 4
(due Friday, September 17)

1. A parallel-plate air-filled capacitor having area 40 cm^2 and plate spacing 1.0 mm is charged to a voltage difference of 600 V . Find (a) the capacitance, (b) the magnitude of the charge on each plate, (c) the stored energy, (d) the electric field between the plates, and (e) the energy density between the plates.
2. In a typical TV or CRT monitor, the current in the electron beam that produces the picture is $200 \mu\text{A}$. How many electrons strike the screen each second?
3. Consider a long, straight string that contains 3×10^{23} electrons and 3×10^{23} protons per meter. The string is stretched out in the east-west direction, and is moving at 1.5 m/s to the east. Throughout this problem, let us call east the positive direction. (a) What is the electric current due only to the electrons in the string (ignoring the protons)? (b) What is the current due only to the protons in the string? (c) What is the net current from both the electrons and protons? (d) Suppose now that an identical string is traveling in the opposite direction at 2.5 m/s . What is the total current of the electrons in both strings (ignoring all the protons)?
4. How long does it take electrons to get from a car battery to the starting motor? Assume that the current is 300 A and that the wire connecting the battery to the motor is copper, with a length of 0.85 m and a cross-sectional area of 0.21 cm^2 . Assume that each copper atom provides one conduction electron. There are 8.5×10^{22} atoms in a cubic centimeter of copper.
5. A $250,000 \mu\text{F}$ capacitor is charged with a 12V battery, then connected to a light bulb and a switch as shown below. When the switch is closed (at $t = 0$), the bulb glows brightly and then rapidly fades. The voltage drop across the capacitor is monitored with a voltmeter during this time, and then plotted in the graph below. Use this graph to estimate the current flowing through the circuit at (or just after) $t = 0$, $t = 1$ second, and $t = 2$ seconds.



6. A human being can be electrocuted if a current as small as 50 mA passes near the heart. When your hands are sweaty, your resistance (between one hand and the other) might be about $2000\ \Omega$. Under these conditions, how careful must you be? How many volts would it take to electrocute you? (A car battery is 12 V, while ordinary house wires are at about 120 V.)
7. A coil is formed by winding 250 turns of 16-gauge copper wire (diameter = 1.3 mm) around a cylinder of radius 12 cm. What is the resistance of the coil? (Look up the resistivity of copper in your textbook.)
8. A typical 120-volt household circuit is protected by a circuit breaker rated at 20 amperes. How much power can this circuit deliver before the circuit breaker is tripped? Explain in some detail why such a device is necessary for safety.
9. Consider two ordinary lightbulbs, both intended to operate at 110 V. One is marked “100 W” while the other is marked “25 W”. For each bulb, compute the current and the resistance under normal operating conditions.
10. Two identical light bulbs are connected in series to a battery, making a single-loop circuit. The bulbs are observed to shine equally bright, even though one is closer than the other to the positive terminal of the battery and is therefore at “higher voltage”. Explain.
11. A particular 12 V car battery is rated “360 ampere-hours”. What kind of a unit is “ampere-hour”? Convert this number to an ordinary SI unit. How much *energy* can this battery store?
12. Make a list of all the appliances and other objects in your home that use a significant amount of electricity. (You may omit minor items like clocks and battery chargers, but be sure to include major items like refrigerators, heating appliances, lightbulbs, and televisions. You may group related items, such as lightbulbs, together for convenience.) For each item, try to estimate the power consumed when it is on, the number of hours it is on per week, and the cost of operation per year assuming that electricity costs \$.07 per kilowatt-hour. (The maximum power consumed is usually written on the appliance somewhere, although some appliances rarely use as much as the maximum. If you can figure out how to read your electric meter, you can watch it for a few hours to determine the power consumption of your refrigerator and whatever else is on at the time.) In this manner, estimate what your total electricity bill should be for one year, and, if you can, compare to an actual bill to check the accuracy of your estimate. If you wanted to reduce your electricity bill, which items would you try to use less or replace with more efficient models?

Study Guide

Electric current is charge per unit time passing any given point:

$$I = \frac{Q_{\text{passing}}}{\Delta t}.$$

The unit of current is the coulomb per second, or ampere (A). You should understand the various minus sign conventions for current due to negative charges and/or charges flowing in opposite directions.

In a single-loop electrical circuit, the current is the same everywhere around the loop. In a circuit with a charging or discharging capacitor, you should be able to relate the current to the time derivative of the charge on the capacitor, or compute the total charge by integrating the current over time (as in problems 3 and 6).

The current that flows through an object (such as a light bulb) depends on the voltage *difference* applied across it. The ratio of volts required to current obtained is called the resistance:

$$R = \Delta V/I.$$

(The unit of resistance is the volt per ampere, or ohm (Ω).) *If* this quantity is approximately independent of the applied voltage, the object is said to obey “Ohm’s law”. The resistance of a wire is proportional to its length and inversely proportional to its cross-sectional area; the constant of proportionality is called the resistivity, ρ :

$$R = \rho \cdot (\text{length})/(\text{area}).$$

The resistivity depends only on the material (and its temperature), not on the size or shape of the wire.

The power (energy per unit time) converted from one form to another in any circuit element is the product of the current and the voltage difference across it:

$$\text{power} = I \cdot \Delta V.$$

(This is just the familiar statement that voltage is energy per unit charge, divided on each side by Δt .)