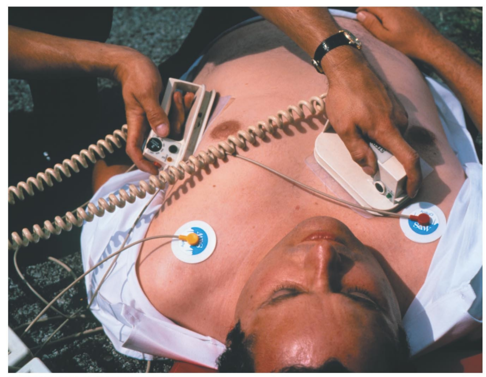
University of Calgary

Department of Physics and Astronomy

PHYS 259, Winter 2017

Labatorial 6: Capacitors

For studying the electric field, we considered a special type of capacitor: parallel plate capacitors, which (in the ideal case) produce a uniform electric field between their plates. In practice, capacitors are important circuit elements that are used for many technical applications. A capacitor can be charged slowly, but releases the stored energy very quickly. A technical application that makes use of this property is a defibrillator. It takes several seconds to charge the capacitor (as you may have observed in various TV shows). The stored energy is then released in a time of the order of milliseconds through the patient's chest, where the electric shock is meant to restore the proper heart beat.



Learning Goals:

To understand the behaviour of capacitors during charging and discharging, and in a circuit.

Preparation:

Halliday, Resnick, and Walker, "Fundamentals of Physics" 10th edition, Wiley: 25.1–25.5 and 27.4.

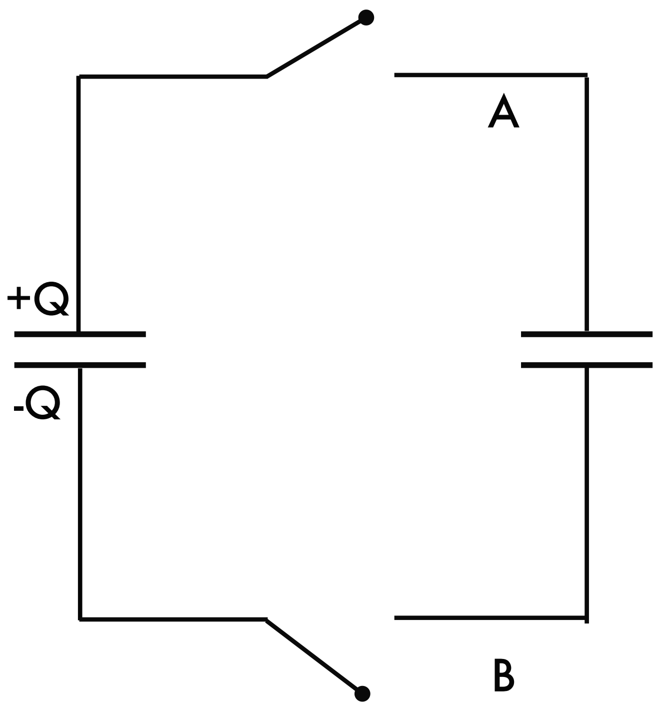
Equipment:

Computer with browser to use the "Circuit Construction Kit (AC/DC)" simulation, developed by the PhET Interactive Simulations Project at the University of Colorado, http://phet.colorado.edu.

Note that there is an equation sheet at the end of this worksheet.

1 Charging and discharging a capacitor

Question 1: The figure shows a circuit with a charged capacitor (left), two switches, and an uncharged capacitor (right). Before the switches are closed, what is the potential difference between the two plates of the uncharged capacitor?



Question 2: First, consider the bottom part of the circuit:

a) *Immediately* after both switches have been closed, is there a potential difference along the wire, i.e. between the bottom plate of the charged capacitor and the bottom plate of the uncharged capacitor? Hint: Consider the distribution of charges at this moment, and consider a real wire with nonzero resistance.

b) Now consider the top part of the circuit and describe whether there is a potential difference along the wire *immediately* after both switches have been closed.

c) What happens to the charge on the bottom plate if the bottom switch is closed but the top switch is left open?

Question 3: If two ammeters were used to measure the current at points A and B while the capacitor on the right is being charged, how would their readings compare?

Question 4: Is there a current flowing between the plates of the capacitor that is being charged? Explain.

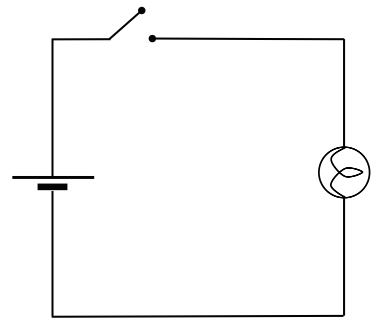
Question 5: What is the potential difference between the plates of the capacitor on the right, compared to the one on the left, when the charging has finished?

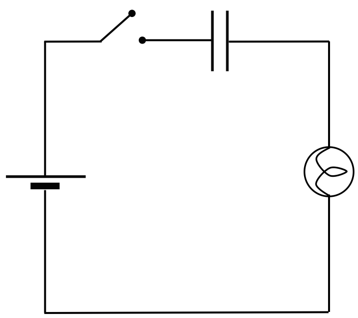
Question 6: What is the potential difference between the top plate of the capacitor on the left and the top plate of the capacitor on the right when the charging has finished?

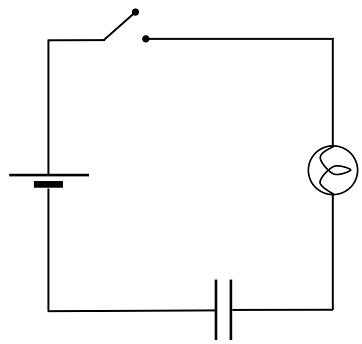
STOP **CHECKPOINT 1: Before moving on to the next part, have your TA check the results you obtained so far.**

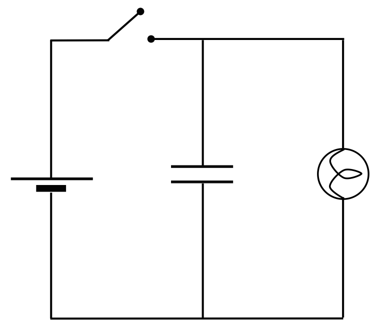
2 A simple circuit with a capacitor

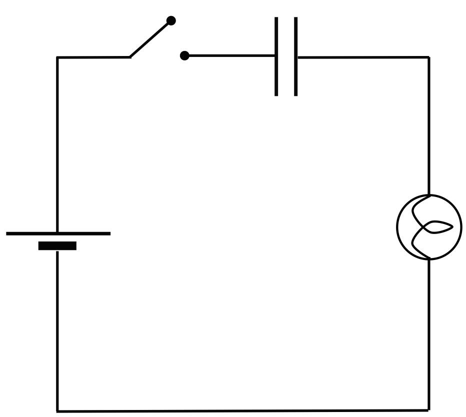
Question 7: The figure to the right shows a simple circuit with a battery and a light bulb. When the connection is briefly broken, as indicated by the open switch, the light bulb will immediately go out. How would you have to include a capacitor in this circuit to ensure that the light bulb stays lit when the connection is briefly interrupted? For each of the possibilities below, explain briefly if it would work or not, and why. Use the simulation "**Circuit Construction Kit**" to test each of the circuits and write down what you observe. In the circuits below, the batteries are assumed to be real (i.e. not ideal) so be sure to include a resistor in the appropriate place in the simulation circuits.









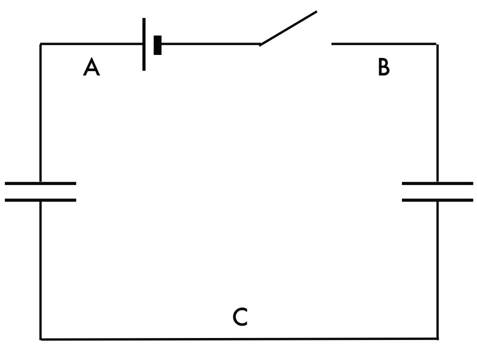


Question 8: The figure shows a circuit with a battery, a switch, a light bulb, and a capacitor. When the switch is closed, will the light bulb light up? Explain your prediction.

Question 9: Test your prediction from the previous question with the Circuit Construction Kit. Explain what you observe in terms of the charge on the capacitor.

CHECKPOINT 2: Before moving on to the next part, have your TA check the results you obtained so far.

3 Charging two capacitors



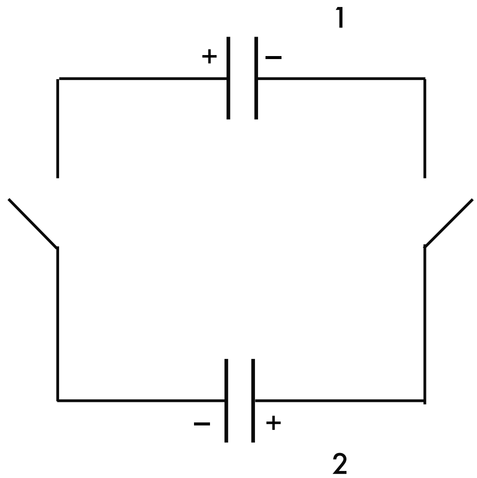
Question 10: The figure shows a circuit with a battery, a switch, and two identical uncharged capacitors.

a) When the switch is closed, the capacitors will be charged. What is the sign of the charge that accumulates on each plate? Draw your answer in the figure.

b) If three ammeters were used to measure the current at points A, B and C while the capacitors are being charged, how would their readings compare? Explain your answer.

c) What is the potential difference across each capacitor, compared to the battery voltage, after the charging has finished?

Question 11: Two capacitors with $C_1 > C_2$ have been charged to the same potential difference $\Delta V_{1i} = \Delta V_{2i}$. Then, their plates are connected with opposite polarity, as shown in the figure.



a) Before the switches are closed, which capacitor stores a bigger charge? Why?

b) After the switches have been closed, which of the following quantities will be the same for both capacitors in the final state: potential difference, charge on each capacitor, capacitance?

c) What is the net initial charge on the left side of the circuit, in terms of C_1, C_2, ΔV_{1i}, and ΔV_{2i}?

d) What is the net final charge on the left side of the circuit? Is it the same or different than part c?

e) Find the final potential difference in terms of the initial potential difference and the capacitances. Hint: Are the charges in parts d and e different or the same? If $C_1 = C_2$, is the result from your calculation consistent with what you would expect?

Last Checkpoint! Clean up your area, and put the equipment back the way you found it. Call your TA over to check your work and your area before you can get credit for the labatorial.

Equations and constants

$$F_C(r) = \frac{1}{4\pi\epsilon_0}\frac{|q_1 q_2|}{r^2}$$
$$\vec{E} = \frac{\vec{F}}{q}$$
$$\vec{E} = -\vec{\nabla}V$$
$$\Delta V = -\int \vec{E}\cdot d\vec{l}$$
$$\Delta U = q\Delta V$$
$$Q(t) = Q_{max}e^{-t/RC}$$
$$Q(t) = Q_{max}(1-e^{-t/RC})$$
$$C = \frac{Q}{\Delta V}$$
$$C = \epsilon_0\frac{A}{d}$$
$$C = KC_0$$
$$U = \frac{Q^2}{2C}$$
$$\Delta V = RI$$
$$R = \frac{\rho L}{A}$$
$$\rho = \frac{E}{J}$$
$$\rho_{Cu} = 1.72\times 10^{-8}\,\Omega m$$
$$\rho_{Ag} = 1.47\times 10^{-8}\,\Omega m$$

$$F_g(r) = G\frac{m_1 m_2}{r^2}$$
$$U_{grav}(y) = mgy$$
$$K = \frac{1}{2}mv^2$$
$$v_x(t) = v_{0x} + a_x t$$
$$x(t) = x_0 + v_{0x}t + \frac{1}{2}a_x t^2$$
$$v_x^2(t) = v_{0x}^2 + 2a_x(x(t)-x_0)$$
$$\omega = \frac{d\theta}{dt}$$
$$v = \frac{2\pi r}{T} = \omega r$$
$$a_{rad} = \frac{v^2}{r} = \omega^2 r$$
$$g = 9.81\frac{m}{s^2}$$
$$G = 6.67\times 10^{-11}\frac{Nm^2}{kg^2}$$
$$\frac{1}{4\pi\epsilon_0} = 8.99\times 10^{9}\,Nm^2C^{-2}$$
$$\epsilon_0 = 8.85\times 10^{-12}\,C^2N^{-1}m^{-2}$$
$$e = 1.60\times 10^{-19}\,C$$
$$m_e = 9.11\times 10^{-31}\,kg$$
$$m_p = 1.67\times 10^{-27}\,kg$$
$$m_n = 1.67\times 10^{-27}\,kg$$