Name: _____

PHYS 1220-02 Quiz 4

You may use an 8.5"×11" note sheet written on both sides, a calculator of any type, and a stuffed toy. Please write your answers in the boxes provided. Show your work outside the boxes. If you wish to change an answer written in a box, thoroughly erase the unwanted answer and write the desired answer in its place. If a numerical answer is a physical quantity rather than a pure number, include the units with your answer.

"Multiple choice" questions, in which only one answer is correct, have circular bubbles (○): select exactly one choice. "Select all" questions, in which any number of the choices may be correct, have square bubbles (☐): select all correct answers. Select your choice by filling the circle or square: please do not "X", check, circle, or otherwise mark your choice. Do not mark bubbles for rejected options.

If the point value of a question is not indicated, it is worth one point.

Constants and equivalents

1 cal = 4.184 J
1 Cal = 1000 cal
1 bar = 10^5 Pa
Specific heat capacity of liquid water: 4184 J/kg
Universal gas constant R: 8.31441 J/(mol·K)
Boltzmann constant k_B: 1.381×10^{-23} J/K
Avogadro's number N_A: 6.022×10^{23}/mol
Stefan-Boltzmann constant σ: $5.670374419 \times 10^{-8}$ W/(m^2·K^4)
Elementary charge e: 1.602×10^{-19} C
Coulomb's constant k: 8.988×10^{9} N·m^2/C^2
permittivity of free space ε_0: 8.854×10^{-12} C^2/(N·m^2)

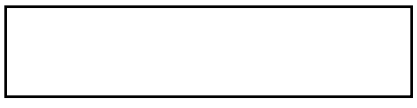
Some metric prefixes

nano	n	$\times 10^{-9}$	deka	D	$\times 10^{1}$
micro	μ	$\times 10^{-6}$	hecta	h	$\times 10^{2}$
milli	m	$\times 10^{-3}$	kilo	k	$\times 10^{3}$
centi	c	$\times 10^{-2}$	mega	M	$\times 10^{6}$
deci	d	$\times 10^{-1}$	giga	G	$\times 10^{9}$

Questions

1. Some physical arrangement of conductors and insulators acts as a capacitor.

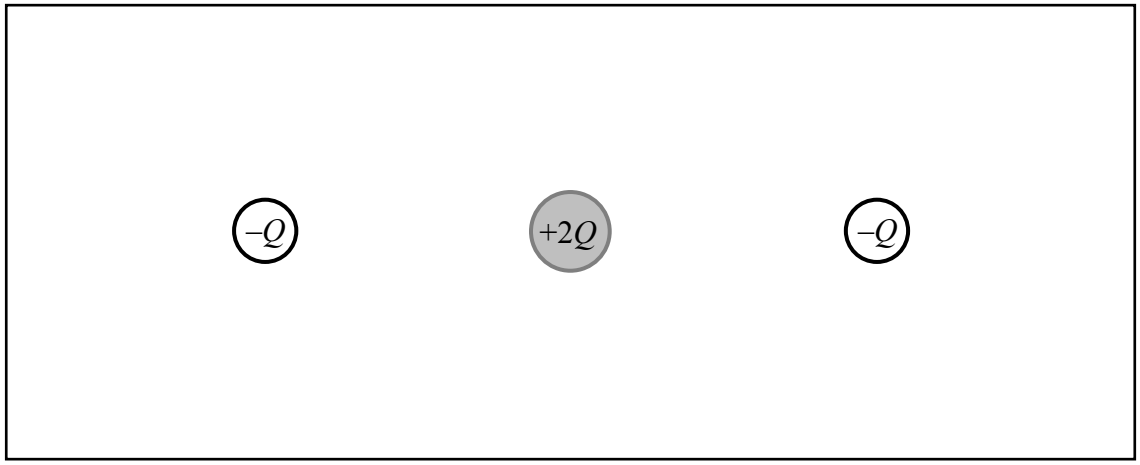
   A. What is the relationship between the charge Q on the conductors, the electric potential V, and the device's capacitance C?

B. What is the relationship between the charge Q on the conductors, the device's capacitance C, and the electric potential energy of the capacitor?

2. Three electric charges are depicted below. A charge of $+2Q$ in the center is flanked by two charges of $-Q$ at opposite positions (equal distances but opposite directions) from the central charge.

A. (2 points) Illustrate the electric field within the boxed region by drawing solid field lines. A knowledgeable viewer shoud be able to understand from the lines alone (no labeling) the direction of the electric field within the boxed region and how the field strength varies from place to place.



B. (2 points) Draw surfaces of constant electric potential as dashed lines within the boxed region. Try to space the lines so that the electric potential difference is the same between any two adjacent lines.

3. A conducting sphere of radius R bears a net electric charge of $+Q$.

A. (2 points) What is the formula for the electric potential at a point in space outside the sphere at a distance r from the center of the sphere ($r > R$)? You may express the formula in terms of R, Q, r, and any necessary physical constants. Assume that there are no other charges or conductors around. Remember that potential at any location is defined as the potential difference from infinitely far away.

B. What is the formula for the electric potential at a point in space outside the sphere at a distance R from the center of the sphere, that is, at the surface of the sphere?

C. What is the formula for the electric potential at a point inside the sphere at a distance r from the center ($r < R$)?

D. Consideration of the formula for the potential at the surface of the sphere reveals that the sphere acts as a capacitor: the electric potential at the surface is directly proportional to the charge the sphere bears. What is the formula for the capacitance of the sphere? Express in terms of R and any necessary constants.

Do you see why the permittivity of free space ε_0 is sometimes given in units of F/m?

E. Suppose the conducting sphere has a radius of 2.00 meters. What is its capacitance?

4. A parallel-plate capacitor is constructed from parallel circular plates with a radius of 0.250 meters. The 1.20×10^{-4}-meter gap between the plates is filled with a dielectric material of dielectric constant $\kappa = 5$ and dielectric strength 12 kV/mm.

   A. (2 points) What is the capacitance of the capacitor?

   B. What is the charge density on the plates when the capacitor bears a charge of 14.5 microcoulombs?

   C. What is the electric field strength *outside* the dielectric (but between the plates) when the capacitor bears this charge?

   D. (2 points) What is the electric field strength *inside* the dielectric when the capacitor bears this charge?

   E. (2 points) What is the breakdown voltage of this capacitor?