- Please tear off the Equation Sheet.
- For Multiple Choice questions, circle the letter of your choice.
- For Short Answer questions, put your answer in the blank provided, with units. In the larger blank areas, show your thinking. This gives you the maximum chance for partial credit.

1. A helium nucleus ($q = +3.2 \times 10^{-19}$ C and $m = 6.64 \times 10^{-27}$ kg) and an proton are near each other. What is the direction of the forces they exert on each other?
   a. The helium nucleus is attracted toward the proton, but the proton is repelled.
   b. The helium nucleus is repelled from the proton, but the proton is attracted.
   c. They are attracted toward each other.
   d. They are repelled from each other.
   e. The force is perpendicular to the imaginary line connecting the particles.

2. A helium nucleus ($q = +3.2 \times 10^{-19}$ C and $m = 6.64 \times 10^{-27}$ kg) and an proton are near each other. Which feels the greater force? (Compare the magnitudes of the forces. Assume the electrostatic force is the only force they experience.)
   a. The forces are the same strength.
   b. The proton feels a stronger force because it is less massive.
   c. The proton feels a stronger force because it has less charge.
   d. The helium nucleus feels a stronger force because it is more massive.
   e. The helium nucleus feels a stronger force because it has more charge.

3. A helium nucleus ($q = +3.2 \times 10^{-19}$ C and $m = 6.64 \times 10^{-27}$ kg) and an proton are near each other. Which has a greater acceleration? (Compare the magnitudes of the accelerations. Assume the electrostatic force is the only force they experience.)
   a. The proton accelerates more rapidly because it is less massive.
   b. The proton accelerates more rapidly because it has less charge.
   c. The helium nucleus accelerates more rapidly because it is more massive.
   d. The helium nucleus accelerates more rapidly because it has more charge.
   e. The accelerations are the same.

4. A balloon that is rubbed against a cotton or wool shirt becomes negatively charged. This ballon can be weakly stuck to a wall. Why does the balloon stick to the wall?
   a. The wall is negatively charged.
   b. The wall is positively charged.
   c. The wall is made entirely of neutral particles, which are attracted to charges.
   d. The wall is charged by the balloon, so that there are more attracted charges than repelled charges.
   e. The wall's charges are shifted by the balloon, so that the attracted charges are closer and make a stronger force.

5. A large positive charge ($Q = +3$ mC) is located at the origin. An electron ($q = -e$) is nearby. If the distance between the charges is decreased, what happens to their potential energy?
   a. It stays the same.
   b. It increases.
   c. It decreases.
   d. The electron's energy decreases, while the positive charge's energy increases.
   e. The electron's energy increases, while the positive charge's energy decreases.

6. A 0.5 F capacitor is charged up to a potential difference of 10 V. What is the (total charge) of the capacitor, including both plates?
   a. 0.5 C
   b. 2.0 C
   c. 0.05 C
   d. 0.0 C
   e. −0.5 C

7. How many electrons does it take to form a coulomb of charge?
   a. 6.25×10^{18} electrons
   b. 1.6×10^{-19} electrons
   c. 9.1×10^{-31} electrons
   d. 1.6×10^{18} electrons
   e. 1.1×10^{30} electrons

8. In a working electrical circuit, the electric current has this behavior:
   a. It is emitted by the battery and absorbed by the load.
   b. It is emitted by the load and absorbed by the battery.
   c. It flows in the air around the wires, in a direction determined by the right-hand rule.
   d. It circulates around the circuit like blood flowing around our cardiovascular system.
       (Note: The "load" is the device using the electricity, such as a light bulb, motor, or resistor.)

9. If an electron beam is pointed straight up into the air, what is the direction of the electric current formed by the beam?
   a. North
   b. South
   c. Upward
   d. Downward
   e. Clockwise, as viewed from the top.
   f. Counter-clockwise, as viewed from the top.

10. If a circuit consists of a battery, an appropriate light bulb, and an ideal ammeter, all in parallel,
    a. The bulb will be lit, but the ammeter will display zero.
    b. The bulb will be lit, and the ammeter will display the bulb's normal operating current.
    c. The bulb will be off, and the ammeter will display zero.
    d. The bulb will be off, and the ammeter will display the bulb's normal operating current.
    e. The bulb will be off, and the ammeter will measure an enormous current.

11. A cylindrical wire has a radius r and a length ℓ. If ℓ and r are cut in half, the resistance of the wire...
    a. Increases.
    b. Decreases.
    c. Remains the same.
    d. It depends on which of r and ℓ is larger.

12. A 14 Ω resistor is connected to a 7.0 V adjustable power supply. If the voltage is doubled, what happens to the resistance?
    a. The resistance increases 4×.
    b. The resistance doubles.
    c. The resistance stays the same.
    d. The resistance is cut in half.
    e. The resistance decreases 4×.

13. Three 60 Ω resistors are placed in **series** and each has 3 V across it. Fill in the table:

	V	I	R	P
Each Resistor	3.0 V	0.05 A	60 Ω	0.15 W
Overall Circuit	9.0 V	0.05 A	180 Ω	0.45 W

14. Three 60 Ω resistors are placed in **parallel** and each has 3 V across it. Fill in the table:

	V	I	R	P
Each Resistor	3.0 V	0.05 A	60 Ω	0.15 W
Overall Circuit	3.0 V	0.15 A	20 Ω	0.45 W

15. What electric field is required to offset the force of gravity on an electron?

Magnitude: _5.6×10^{-11} N/c_

Direction: _Down_

16. A computer uses a power of 150 W, and electricity costs $0.12/kWh, calculate how much money is spent in 720 hours (i.e. 1 month) of continuous operation.

Answer: _$12.96_

17. What is the resistance of a 25 ft, 14 gauge extension cord? The wire diameter is 1.63 mm, and 1 ft = 0.3048 m. The resistivity of copper is about 1.71×10^{-8} Ω · m. Don't forget that the effective length of the wire should be doubled because the current is carried out to the device and back to the outlet.

Answer: _0.125 Ω_

$$R = \rho \frac{\ell}{A} = (1.71 \times 10^{-8} \Omega \cdot m) \frac{(50 \, ft)(0.3048 \frac{m}{ft})}{\pi (0.00163 \, m/2)^2}$$
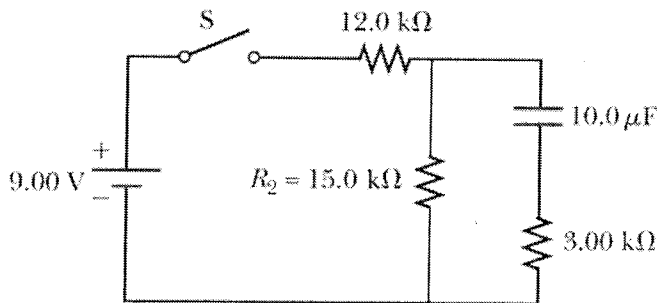
Figure: Circuit used in the next two questions.

18. In the figure above, the switch has been closed for a long time, so that the capacitor is as charged as it is going to get. What is the voltage of the capacitor? (Hint: It's not 9.0 V. Figure out how much curretn flows through the 12 kΩ resistor.)

Answer: ___5.0   V___

$$I = \frac{\varepsilon}{(12 k\Omega + 15 k\Omega)}$$

$$V_C = V_{15k} = (I)(15 k\Omega)$$

19. In the figure above, the switch has been closed for a long time. Then, the switch is opened, removing the battery from the circuit. What is the time constant τ of the discharge process?

Answer: ___0.18   s___

$$R = 18 k\Omega$$

$$\tau = RC$$

20. The bottom of a thundercloud is 2400 m above Earth's surface. The cloud has an area of 9 km^2. Assume that the cloud and the part of Earth's surface underneath it form a perfect capacitor. What is the capacitance of the thundercloud-Earth system? (Assume the dielectric constant is equal to one.)

Answer: ___3.3×10^{-8} F___

$K = 1 = $ dielectric const

$$C = \frac{K\varepsilon_0 A}{d} = \frac{(1)(8.85 \times 10^{-12} \frac{C^2}{N m^2})(9 \times 10^6 m^2)}{2400 m}$$

21. The bottom of a thundercloud is 2400 m above Earth's surface. The cloud has an area of 9 km^2. If the air can support an electric field of 10^6 N/C, how much charge can build up in the thundercloud?

Answer: ___80   C___

$$Q = CV$$

$$V_{max} = E_{max} d$$
$$= 2.4 \times 10^9 V$$

DC Circuits

This schematic is a model of a cell phone battery, screen, and charger.

- The phone circuitry automatically adjusts R_{screen} so its current is 0.25 A.
- The 4.5 V battery has R_{batt} of internal resistance, which we will consider to be a separate resistor.
- The battery draws a charging current of 0.75 A. This is accomplished by adjusting R_{batt}.
- The 5.0 V charger has 0.3 Ω of internal resistance, which we will consider to be a separate resistor.
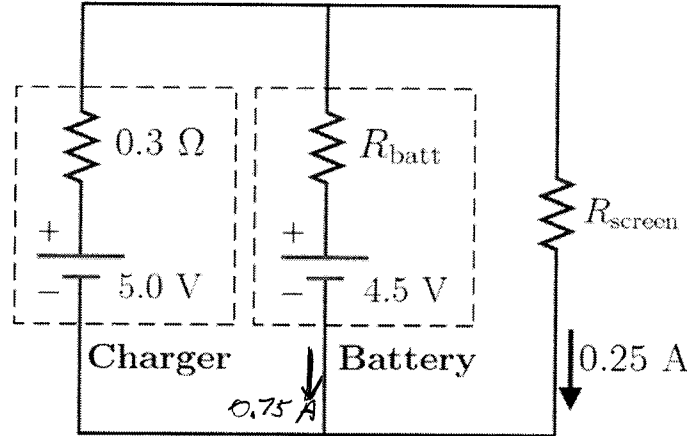
Figure: Cell Phone charger (left), battery (middle), and screen (right). The charger supplies enough energy to run the screen and charge the battery. The ideal battery symbols represent the EMF ($\mathcal{E}$) portion of the batteries, and the internal resistances are represented separate resistors.

22. Fill in the missing values.

Component	Voltage Across	Current Through	Resistance
R_{screen}	4.7 V	0.25 A	17.6 Ω
R_{batt}	0.2 V	0.75 A	0.27 Ω
$\mathcal{E}_{batt}$	4.5 V	0.75 A	n/a
$R_{charger}$	0.3 V	1.0 A	0.3 Ω
$\mathcal{E}_{charger}$	5.0 V	1.0 A	n/a

① Charger must supply 1.0 A total.
② $R_{charger}$ drops 0.3 V.
③ R_{screen} drops 4.7 V.
④ R_{batt} must drop 0.2 V = 4.7 V − 4.5 V
⑤ Ohm's Law to find R_{screen}, R_{batt}.