Name(s) ____________________
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Per. ______

E-V.1 **DIRECT CURRENT ELECTRIC CIRCUITS**

Part I - Circuit Elements in Series

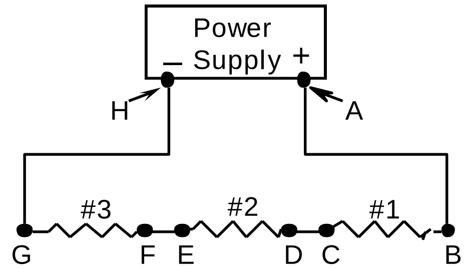

Figure 1

In Figure 1 at the right circuit elements #1, #2, #3 (in this case light bulbs) are said to be connected "IN SERIES". That is, they are connected in a series one right after the other. Your first task is to measure the electric CURRENT flowing in different parts of this series circuit. Electric current is the number of charges per unit time that pass a point in a circuit. In the SI system of units the unit of current is the AMPERE (abbreviated A or amp), where, by definition:

1 AMPERE = 1 COULOMB/SECOND (M,L,T,Q units: Q/T)

If 1 coulomb of charge passes a point in a circuit in 1 second, then 1 ampere of current is flowing past the point. The currents being measured in this experiment will be of the order of thousandths of an ampere, or milliamps (abbreviated: mA), where 1 mA is 1/1000 A. Connect the current meter (aka ammeter) as instructed in class and measure the current between the points listed in Table I.

TABLE I.

Location of Ammeter	Current (mA)
Between* A & B	____________
Between C & D	____________
Between E & F	____________
Between G & H	____________

*The use of the word **between** is to remind you to hook up the ammeter **between** the two points

Using the data in Table I, answer the following. Include proper units with each answer.

Q-1 What can you conclude about the current at any point in a series circuit?

____

Q-2 How many coulombs of charge leave the power supply during each second?

____

Q-3 How many coulombs of charge move from bulb #2 to bulb #3 during each 5 second interval?

____

Q-4 How many coulombs of charge arrive at the negative terminal of the power supply in each second?

____

Q-5 Recall that 1 coulomb is about 6.25 X 10^{18} elementary charges (e.c.). How many individual elementary charges pass through bulb #2 during each second?

____

E-V.1 **DIRECT CURRENT ELECTRIC CIRCUITS**

Remove the ammeter from the circuit. As demonstrated in class, use the voltmeter to measure the potential difference (abbreviated: PD or VOLTAGE) across each light bulb and across the power supply. Record your measurements in Table II.

TABLE II.	Location of voltmeter	PD (Volts)
	Across bulb #1	____________
	Across bulb #2	____________
	Across bulb #3	____________
	Across the Power Supply	____________

*The use of the word **across** is to remind you to hook up the voltmeter **across** the circuit element**.**

Let's see what these potential differences (or voltages) mean in a physical sense. Assume that positive charges are the only charges that flow in the circuit. (Equivalent arguments can be made for negative charge flow giving the same results.) Notice in Figure 1 that there is a positive and a negative terminal on the power supply. Since there is an excess positive charge on the positive terminal each individual positive charge at that terminal experiences a repulsive force due to the other positive charges. Each positive charge at the positive terminal then, has electrical potential energy. When an external circuit is attached to the power supply the positive charges flow around through the circuit losing electrical potential energy on theirt way to the negative terminal. As they arrive at the negative terminal, the power supply has the characteristic that it forces these positive charges to move internally through the power supply from the negative to the positive terminal, thereby again increasing their electrical potential energy. The change in electrical potential energy per unit charge is called the change in electric potential or the POTENTIAL DIFFERENCE (or VOLTAGE) between the terminals. If the energy of the charges is measured in units of joules and the charge in coulombs then the potential difference has units of joules per coulomb. The SI unit of potential difference is the VOLT (abbreviated: V), where, by definition:

1 VOLT = 1 JOULE/COULOMB (M,L,T,Q unit: ML^2/T^2Q)

Thus, the PD (voltage) across any circuit element is a measure of the difference in potential energy per unit charge on one side of the circuit element as opposed to the other side of the element. For example, if a battery has a PD of 1.5 volts between its terminals, this means that the battery increases the potential energy of each coulomb of positive charge passing through the battery from the negative to the positive terminal by 1.5 joules.

Using the definition of PD given above and the data from Table II, fill in the following. Again, be sure to include proper units with each answer.

The voltage (PD) between the terminals of the power supply was (I-1) ____________. This

means that each coulomb of charge gained (I-2) ____________ of potential energy as it passed from the negative to the positive terminal within the power supply, or that each 1/2 C of

charge gained (I-3) ____________ of PE, or that each 5 C gained (I-4) ____________ of PE.

It also means that each individual elementary charge gained (I-5) ____________ of potential energy as it passed through the power supply.

E-V.1 **DIRECT CURRENT ELECTRIC CIRCUITS**

Consider what happens to the charges as they flow through the external circuit. Assume that the charges lose no energy in the wires between the light bulbs. As they move through each bulb, some of the electrical potential energy of the charges is converted into heat and light energy. The voltage (PD) across each bulb tells us how much energy is converted per coulomb of charge passing through the bulb. For example, the voltage (PD) across bulb #1 was measured to be (I-6) ____________. This means that each coulomb of charge passing through bulb #1 had (I-7) ____________ of its potential energy converted to heat and light energy. Each coulomb also gave up (I-8) ____________ of PE as it passed through bulb #2 and (I-9) ____________ as it passed through bulb #3. The amount of PE given up by each individual elementary charge in bulb #1, #2, and #3 was (I-10) ___________, ___________, and ____________.

Q-6 What was the TOTAL amount of potential energy lost by each coulomb of charge passing through bulbs #1, #2, and #3 from the positive terminal (point A) of power supply to the negative terminal (point H)?

____

Q-7 How much potential energy was initially given to each coulomb of charge by the power supply?

____

Q-8 How does the potential energy per unit charge (aka the voltage) supplied by the power supply compare with the total potential energy per unit charge (aka voltage) given up as the charges move through the light bulb circuit?

____

From your answers to Q-6, 7, and 8 you should recognize THE LAW OF CONSERVATION OF ENERGY. Let's restate your conclusion stated in Q-8:

THE SUM OF ALL THE POTENTIAL ENERGY INCREASES PER UNIT CHARGE EQUALS THE SUM OF ALL THE POTENTIAL ENERGY DECREASES PER UNIT CHARGE AROUND A CLOSED LOOP IN A CIRCUIT.

Or, since potential energy increases per unit charge means a voltage increase and potential energy decrease per unit charge means a voltage decrease, then the above can be restated as:

THE SUM OF THE VOLTAGE INCREASES EQUALS THE SUM OF ALL THE VOLTAGE DECREASES AROUND A CLOSED LOOP IN A CIRCUIT.

E-V.1 **DIRECT CURRENT ELECTRIC CIRCUITS**

Recall that power is the energy transferred into or out of a system per unit time. For example, if a battery supplies 2.5 joules of energy to a circuit every 5 seconds then it is supplying energy at the rate of 2.5 joules/5 seconds or 0.5 joule/sec. The SI unit of power is the WATT (abbreviated: W), where, by definition,

1 WATT = 1 JOULE/SECOND (M,L,T,Q unit: ML^2/T^3)

The battery then, is supplying energy to the circuit at a rate of 0.5 joule/second or 0.5 watt.

Let's relate the power supplied or dissipated in a circuit to the current and voltage. Suppose there is a current of 1/4 ampere flowing through a circuit element and the voltage across the element is 6 volts. A current of 1/4 ampere means that (I-11)__________ coulomb(s) of charge pass through the circuit element each second. A potential difference of 6 volts across the element

means that each coulomb passing through the circuit element loses (I-12) ____________ of potential energy. Therefore, (I-13) ____________ of electrical potential energy is given up by the charges each second as they flow through the circuit element.

Q-9 The power dissipated is the energy given up by the charges per unit time. What is the power dissipated in the circuit element in the above example? ____________________

Note that the same answer to Q-9 can also be found by multiplying the current through the element by the potential difference across it. That is,

POWER = (CURRENT)(VOLTAGE) or P = (I)(V)

Comparing the units we can see that if the current is in amperes and PD in volts then,

$$(\text{AMPERE})\text{X}(\text{VOLT}) = \frac{\text{COULOMB}}{\text{SECOND}} \text{X} \frac{\text{JOULE}}{\text{COULOMB}} = \frac{\text{JOULE}}{\text{SECOND}} = \text{WATT}$$

Using your data from Tables I and II calculate the following:

i. The power supplied by the power supply (Units!!):

P_s = (____________)(____________) = ____________

ii. The power dissipated in bulb #1:

P_1 = (____________)(____________) = ____________

iii. The power dissipated in bulb #2:

P_2 = (____________)(____________) = ____________

iv. The power dissipated in bulb #3

P_3 = (____________)(____________) = ____________

v. The total power dissipated in all three bulbs:

$P_1 + P_2 + P_3$ = ____________

Q-10 How does the power supplied compare with the total power dissipated in the bulbs?

____

E-V.1 **DIRECT CURRENT ELECTRIC CIRCUITS**

PART II - Circuit Elements in Parallel

The circuit for Part II is shown in Figure 2. As in Part I, the circuit elements are small light bulbs. The bulbs marked #1 and #2 are said to be connected "IN PARALLEL" since they are connected to common points (B & G) in such a way that the current flowing in each element flow parallel to one another. Note that bulbs #3 and #4, and the power supply are connected in SERIES.

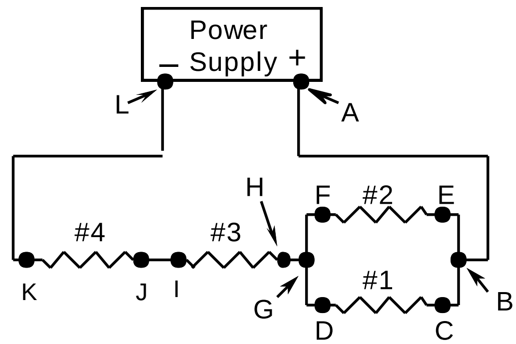

Figure 2

Connect the ammeter between the points listed in Table III and measure the current flowing out of the power supply (I_{AB}), the current through bulb #1 (I_{BC}), through #2 (I_{BE}), through #3 (I_{GH}), through #4 (I_{IJ}), and flowing back into the power supply (I_{KL}). Record these measurements in Table III.

TABLE III.

Location of Ammeter	Current (mA)
Between* A & B	____________
Between B & C	____________
Between B & E	____________
Between G & H	____________
Between I & J	____________
Between K & L	____________

*Again the use of the word **between** is to remind you to hook up the ammeter **between** the two points

Q-11 Referring to Table III, how does the sum of the currents in the parallel elements (I_{BC} + I_{BE}) compare with the current in the rest of the circuit?

____

If you have measured the current through bulb #1 (I_{BC}) and #2 (I_{BE}) correctly and answered Q-11 you discovered an important characteristic about the current in circuit elements connected in parallel:

THE SUM OF THE CURRENTS IN PARALLEL CIRCUIT ELEMENTS EQUALS THE CURRENT FLOWING INTO AND OUT OF THE PARALLEL COMBINATION.

Remove the ammeter from the circuit. Using a voltmeter, measure the potential differences (voltages) across each of the circuit elements and record them in Table IV.

E-V.1 **DIRECT CURRENT ELECTRIC CIRCUITS**

TABLE IV.

Location of voltmeter	PD (Volts)
Across bulb #1	____________
Across bulb #2	____________
Across bulb #3	____________
Across bulb #4	____________
Across the Power Supply	____________

*Again the use of the word **across** is to remind you to hook up the voltmeter **across** the circuit element.

Q-12 How does the potential energy lost by each coulomb of charge passing through bulb #1 compare with the potential energy lost by each coulomb passing through bulb #2?

____

If you measured the voltages (PD) across bulbs #1 and #2 correctly and answered Q-12, you discovered an important characteristic of the voltage across circuit elements connected in parallel:

THE VOLTAGES ACROSS PARALLEL CIRCUIT ELEMENTS ARE EQUAL.

Refer to Table IV and fill in the following : The potential energy gained by each coulomb of charge passing through the power supply was (II-1)____________. The potential energy lost by each coulomb of charge that passed through bulb #1 was (II-2)___________. The potential energy lost by each coulomb that passed through bulb #2 was (II-3)___________. … through bulb #3 was (II-4)_____________ .... through bulb #4 was (II-5)___________.

Suppose 1 coulomb of charge moves through the closed loop that includes the power supply, bulb #1, bulb #3, and bulb #4. Compare the increases in its potential energy with the decreases as the charge moves along this path.

(II-6) PE increases = _____________ PE decreases = _____________

Suppose another coulomb of charge moves through the closed loop that includes the power supply, bulb #2, bulb #3, and bulb #4. Compare the increases in its potential energy with the decreases as the charge moves along this path.

(II-7) PE increases = _____________ PE decreases = _____________

Q-13 Referring to the comparisons above, does the rule stated in Part I for series circuits "THE SUM OF VOLTAGE INCREASES EQUALS THE SUM OF ALL THE VOLTAGE DECREASES AROUND ANY CLOSED LOOP IN A CIRCUIT" hold also for circuits containing elements that are connected in parallel? Explain.

____

____

E-V.1 **DIRECT CURRENT ELECTRIC CIRCUITS**

Suppose three circuit elements, #1, #2, and #3, are connected as shown in Figure 3 and the currents I_{in}, I_1, I_2, I_3, and I_{out} are measured along with the potential differences V_1, V_2, and V_3 across each element. In the light of the conclusions arrived at in Part II, answer the following.

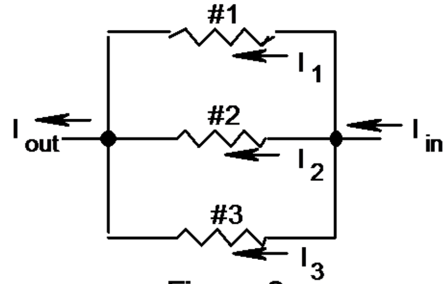

Figure 3

Q-14 How should I_{in} compare with I_{out}?

____

Q-15 How should the sum $I_1 + I_2 + I_3$ compare with I_{in} and I_{out}?

____

Q-16 How should V_1, V_2, and V_3 compare?

____

POWER IN PARALLEL CIRCUITS

Using data from Tables III and IV, calculate the following (<u>Units!!</u>):

i. The power supplied by the power supply:

P_s = (_____________)(_____________) = _____________

ii. The power dissipated in bulb #1:

P_1 = (_____________)(_____________) = _____________

iii. The power dissipated in bulb #2:

P_2 = (_____________)(_____________) = _____________

iv. The power dissipated in bulb #3

P_3 = (_____________)(_____________) = _____________

v. The power dissipated in bulb #4

P_4 = (_____________)(_____________) = _____________

vi. The total power dissipated in all four bulbs:

$P_1 + P_2 + P_3 + P_4$ = _____________

Q-17 How does the power supplied by the power supply compare with the <u>total</u> power dissipated in the bulbs?

____

E-V.1 **DIRECT CURRENT ELECTRIC CIRCUITS**

PART III - Ohm's Law

The circuit for Part III is shown in Figure 4. In the diagram the symbol R represents a resistor, (A) represents an ammeter and (V) represents a voltmeter. In this part of the experiment the output voltage of the power supply will be varied and the resulting voltage across the resistor and the current through it will be measured.

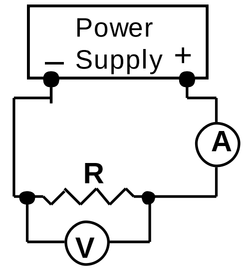

Figure 4

Assemble the circuit shown in Figure 4 using the resistor supplied. Vary the output of the power supply so that the current through the resistor varies over a range of approximately 10 to 100 mA. Measure the corresponding voltages across the resistor. Record the data in Table V.

TABLE V.

PD Across R in volts	Current Through R in mA	Current Through R in amps

Graph the potential difference across the resistor in volts (vertically) versus the current through the resistor in amperes (horizontally).

From the graph it can be concluded that: (III-1) $V_{across\ R} \propto$ ______

Restating this conclusion: Since the potential difference (or voltage) across a resistor is directly proportional to the current flowing through the resistor, the voltage is equal to a constant of proportionality times the current. In other words,

V = (R)(I)

where R represents the constant of proportionality between the voltage and the current.

E-V.1 **DIRECT CURRENT ELECTRIC CIRCUITS**

The constant R is called the RESISTANCE of the resistor. It is a measure of the resistor's ability to impede the flow of charge through it. For a given voltage, the larger the value of R the smaller the amount of current that will flow through the resistor. For the resistor used in this part of the experiment the numerical value of R can be found by determining the slope of the V versus I graph.

Q-18 What was the resistance R of the resistor used in this part of the experiment? Be sure to include its units from the graph! Slope of V vs I graph = R = ________________

The SI unit of resistance is the OHM (abbreviation: Ω), where, by definition:

1 OHM = 1 Ω = 1 VOLT/AMP (M,L,T,Q unit: ML^2/TQ^2)

The equation V = (R)(I) is called OHM'S LAW. Assume that the light bulbs used in Parts I and II obey Ohm's Law and calculate the following resistances:

(III-3) R of bulb #1 in Part I = (_________) ÷ (_________) = __________

(III-4) R of bulb #1 in Part II = (_________) ÷ (_________) = __________

(III-5) R of bulb #2 in Part II = (_________) ÷ (_________) = __________