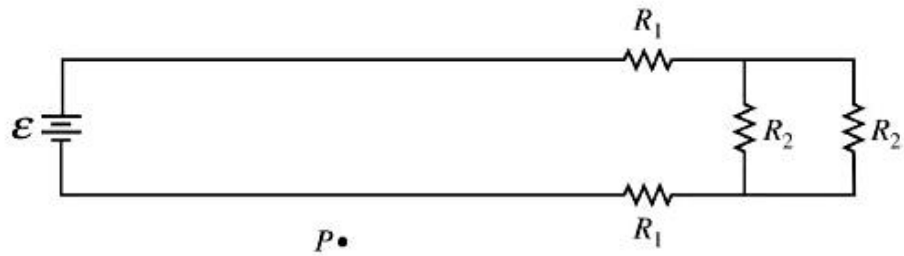
PHY132 Review Problems

For Exam 2

(Ch. 24-27 Giancoli)



1) (10 points)

In the circuit above, the battery of emf ε is connected to two long, straight, parallel wires, which in turn are connected to four resistors with resistances given in the figure above. Assume that any other resistances in the circuit are negligible. Express all algebraic answers to the following parts in terms of the given quantities and fundamental constants.

(a) Derive an expression for the total resistance of the circuit.

(b) Derive an expression for the power dissipated in this circuit.

Assume that any magnetic fields result only from the currents in the two long wires.

(c) What is the direction of the magnetic field, if any, at point *P*, which is in the plane of the page?

____ To the left ____ Toward the top of the page ____ Out of the plane of the page

____ To the right ____ Toward the bottom of the page ____ Into the plane of the page

____ None of the above, because the magnetic field is zero

Explain your reasoning.

(d) What is the direction of the force, if any, on the bottom wire due to the current in the top wire?

____ To the left ____ Toward the top of the page ____ Out of the plane of the page

____ To the right ____ Toward the bottom of the page ____ Into the plane of the page

____ None of the above, because the force is zero

Explain your reasoning.

(a) 2 points

For correctly determining the equivalent resistance of the two parallel resistors — 1 point

$$\frac{1}{R_p} = \frac{1}{R_2} + \frac{1}{R_2} = \frac{2}{R_2}$$

$$R_p = \frac{1}{2}R_2$$

For correctly determining the total equivalent resistance of the circuit — 1 point

$$R_T = R_1 + R_1 + R_p$$

$$R_T = 2R_1 + \frac{1}{2}R_2$$

(b) 2 points

For a correct expression for the power in terms of emf and resistance — 1 point

$$P = \mathcal{E}^2 / R_T$$

For correctly substituting the value of total resistance from part (a) — 1 point

$$P = \mathcal{E}^2 \Big/ \left(2R_1 + \frac{1}{2}R_2\right)$$

(c) 3 points

For correctly indicating that the field is directed out of the plane of the page — 1 point

For using the right-hand rule to determine the direction of the field at point P from each wire (into the page from the top wire, out of the page from the bottom wire) — 1 point

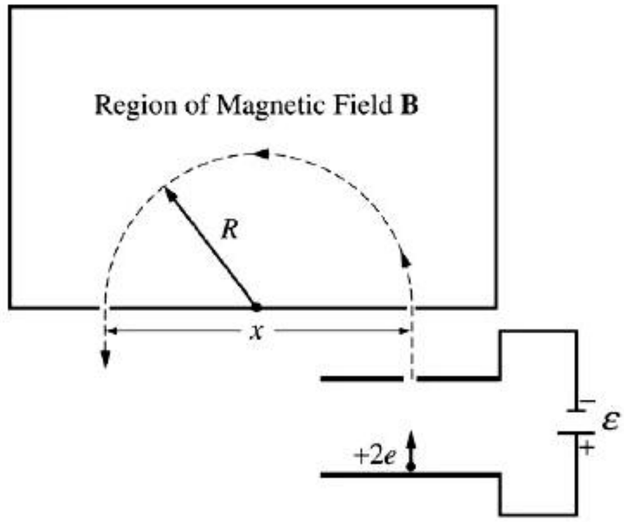
For indicating that the magnitude of the field at point P from the bottom wire is greater because it is closer to point P — 1 point

(d) 3 points

For correctly indicating that the force is directed toward the bottom of the page — 1 point

For indicating that the magnetic field at the bottom wire due to the top wire is directed into the page — 1 point

For using the right-hand rule to determine the direction of the force on the bottom wire due to the magnetic field — 1 point



Top View

2. (10 points)

Your research director has assigned you to set up the laboratory's mass spectrometer so that it will separate strontium ions having a net charge of $+2e$ from a beam of mixed ions. The spectrometer above accelerates a beam of ions from rest through a potential difference $\mathcal{E}$, after which the beam enters a region containing a uniform magnetic field **B** of constant magnitude and perpendicular to the plane of the path of the ions. The ions leave the spectrometer at a distance x from the entrance point. You can manually change $\mathcal{E}$.

Numerical values for this experiment:

Strontium atomic number:	38
Strontium ion mass:	1.45×10^{-25} kg
Magnitude of B field:	0.090 T
Desired exit distance x:	1.75 m

(a) In what direction must **B** point to produce the trajectory of the ions shown?

(b) The ions travel at constant speed around the semicircular path. Explain why the speed remains constant.

(c) Calculate the speed of the ions with charge $+2e$ that exit at distance x.

(d) Calculate the accelerating voltage $\mathcal{E}$ needed for the ions with charge $+2e$ to attain the speed you calculated in part (c).

(a) 1 point

For correctly indicating that the direction of the field is INTO the page or in the $-z$ direction. 1 point

(b) 2 points

For stating that the (magnetic) force is perpendicular to the velocity, or the force is centripetal, or an equivalent concept. 1 point

Note: The use of the phrase "centripetal force," without stating its source, earned no credit.

For stating that the (magnetic) force or field changes the direction of the velocity but not the speed, or an equivalent concept. 1 point

(c) 4 points

For a correct expression indicating that the magnetic force provides the centripetal force 1 point

$$\frac{mv^2}{R} = qvB$$

For a correct calculation of the radius of the trajectory 1 point

$$R = \frac{x}{2} = \frac{1.75 \text{ m}}{2} = 0.875 \text{ m}$$

For correct substitutions into a correct expression 1 point

$$v = \frac{qBR}{m} = \frac{2(1.60 \times 10^{-19} \text{ C})(0.090 \text{ T})(0.875 \text{ m})}{1.45 \times 10^{-25} \text{ kg}}$$

For a correct answer with units 1 point

$$v = 1.74 \times 10^5 \text{ m/s}$$

(d) 3 points

For a correct expression indicating an equivalence of work and energy or electric potential energy and kinetic energy 1 point

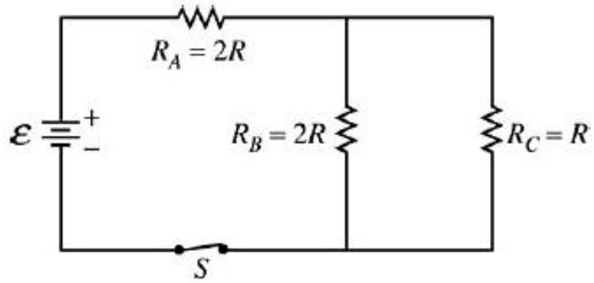
$$q\mathcal{E} = \frac{1}{2}mv^2$$

For correct substitutions into a correct expression 1 point

$$\mathcal{E} = \frac{1}{2}\frac{m}{q}v^2 = \frac{1}{2}\frac{(1.45 \times 10^{-25} \text{ kg})}{2(1.60 \times 10^{-19} \text{ C})}(1.74 \times 10^5 \text{ m/s})^2$$

For a consistent answer with units 1 point

$$\mathcal{E} = 6860 \text{ V}$$



3. (15 points)

The circuit above contains a battery with negligible internal resistance, a closed switch S, and three resistors, each with a resistance of R or $2R$.

(a)

i. Rank the currents in the three resistors from greatest to least, with number 1 being greatest. If two resistors have the same current, give them the same ranking.

____ I_A ____ I_B ____ I_C

ii. Justify your answers.

(b)

i. Rank the voltages across the three resistors from greatest to least, with number 1 being greatest. If two resistors have the same voltage across them, give them the same ranking.

____ V_A ____ V_B ____ V_C

ii. Justify your answers.

For parts (c) through (e), use $\mathcal{E} = 12$ V and $R = 200\ \Omega$.

(c) Calculate the equivalent resistance of the circuit.

(d) Calculate the current in resistor R_C.

(e) The switch S is opened, resistor R_B is removed and replaced by a capacitor of capacitance 2.0×10^{-6} F, and the switch S is again closed. Calculate the charge on the capacitor after all the currents have reached their final steady-state values.

(a)

(i) 2 points

For ranking I_A as the greatest — 1 point

For ranking I_C as the second greatest and I_B as the third greatest — 1 point

(ii) 2 points

For a correct statement justifying that I_A is greatest. (For example: The total current flows through R_A and gets divided between the other two resistors.) — 1 point

For a correct statement justifying that I_C is second and I_B is third. (For example: R_B and R_C share the current in the parallel segment, and that current divides between R_B and R_C so that the smaller resistor R_C carries the most current.) — 1 point

(b)

(i) 1 point

For the correct ranking V_A, V_B, V_C = 1, 2, 2 — 1 point

(ii) 2 points

For a correct justification that V_A is the greatest. (For example, because no resistor is greater than R_A, and R_A has the full current through it. Or, because R_A is greater than the equivalent parallel resistance of R_B and R_C.) — 1 point

For a correct justification that $V_B = V_C$. (For example, since the voltage across the parallel resistors R_B and R_C is the same.) — 1 point

(c) 3 points

Let R_{BC} be the resistance of the parallel combination of R_B and R_C.

For one correct form for determining R_{BC} — 1 point

$$\frac{1}{R_{BC}} = \frac{1}{R_B} + \frac{1}{R_C} = \frac{1}{2R} + \frac{1}{R} = \frac{1}{400\ \Omega} + \frac{1}{200\ \Omega} = \frac{3}{400\ \Omega}$$

$$R_{BC} = \frac{2R}{3} = \frac{400\ \Omega}{3} = 133\ \Omega$$

For one correct form for determining the total resistance — 1 point

$$R_{tot} = R_A + R_{BC} = 2R + \frac{2R}{3} = 400\ \Omega + 133\ \Omega$$

For the correct numerical value — 1 point

$$R_{tot} = 533\ \Omega$$

(d) 3 points

For one correct form for the current I_A, using R_{tot} from part (c) — 1 point

$$I_A = \frac{\varepsilon}{R_{tot}} = \frac{12\ \text{V}}{533\ \Omega} = 0.0225\ \text{A}$$

For the correct value of V_C — 1 point

$$V_C = \varepsilon - V_A = \varepsilon - I_A R_A = 12\ \text{V} - (0.0225\ \text{A})(400\ \Omega) = 3.0\ \text{V}$$

$$I_C = \frac{V_C}{R_C} = \frac{3\ \text{V}}{200\ \Omega}$$

For the correct numerical value of I_C — 1 point

$$I_C = 0.015\ \text{A}$$

Alternate solution — *Alternate points*

Using $R_B = 2R_C$ and $V_B = V_C$ so that $I_B R_B = I_C R_C$

$$I_C = \frac{R_B}{R_C} I_B = \frac{2R_C}{R_C} I_B = 2I_B$$

For the correct numerical value for I_{tot} — *1 point*

$$I_{tot} = \varepsilon / R_{tot} = 0.0225\ \text{A}$$

For correctly relating I_{tot} to I_C — *1 point*

$$I_{tot} = I_B + I_C = \frac{I_C}{2} + I_C = \frac{3I_C}{2}$$

For the correct numerical value of I_C — *1 point*

$$I_C = \frac{2I_{tot}}{3} = \frac{2}{3}(0.0225\ \text{A}) = 0.015\ \text{A}$$

(e) 2 points

In the new circuit, $I_B = 0$ at equilibrium, so the total current goes through each of the two resistors

$$I_{tot} = \frac{\varepsilon}{R_A + R_C} = \frac{\varepsilon}{2R + R} = \frac{\varepsilon}{3R} = \frac{12\ \text{V}}{600\ \Omega} = 0.02\ \text{A}$$

For the correct value of the voltage across the capacitor — 1 point

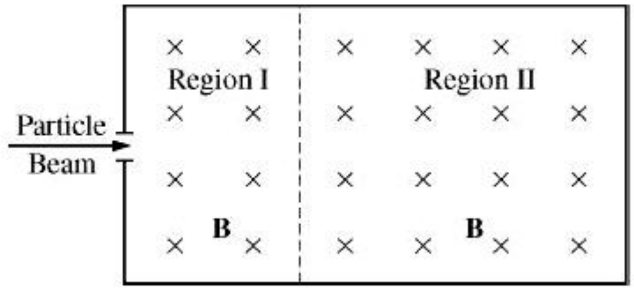
$$V_C = I_{tot} R_C = (0.02\ \text{A})(200\ \Omega) = 4.0\ \text{V}$$

$$Q = CV_C$$

$$Q = (2.0 \times 10^{-6}\ \text{F})(4.0\ \text{V})$$

For the correct numerical value of Q — 1 point

$$Q = 8.0 \times 10^{-6}\ \text{C}$$



4) (10 points)

A beam of particles of charge $q = +3.2 \times 10^{-19}$ C and mass $m = 6.68 \times 10^{-26}$ kg enters region I with a range of velocities all in the direction shown in the diagram above. There is a magnetic field in region I directed into the page with magnitude $B = 0.12$ T. Charged metal plates are placed in appropriate locations to create a uniform electric field of magnitude $E = 4800$ N/C in region I. As a result, some of the charged particles pass straight through region I undeflected. Gravitational effects are negligible.

(a)

i. On the diagram above, sketch electric field lines in region I.

ii. Calculate the speed of the particles that pass straight through region I.

The particles that pass straight through enter region II in which there is no electric field and the magnetic field has the same magnitude and direction as in region I. The path of the particles in region II is a circular arc of radius R.

(b) Calculate the radius R.

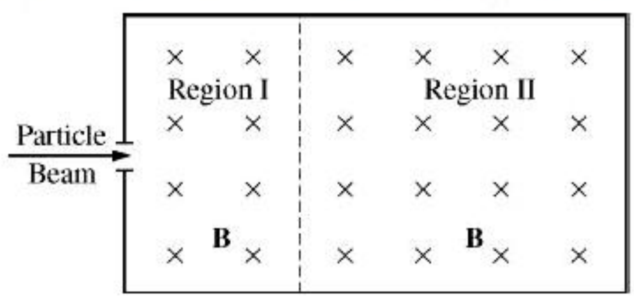
(c) Within the beam there are particles moving slower than the speed you calculated in (a)ii. In what direction is the net initial force on these particles as they enter region I?

____ To the left　　____ Toward the top of the page　　____ Out of the plane of the page

____ To the right　　____ Toward the bottom of the page　　____ Into the plane of the page

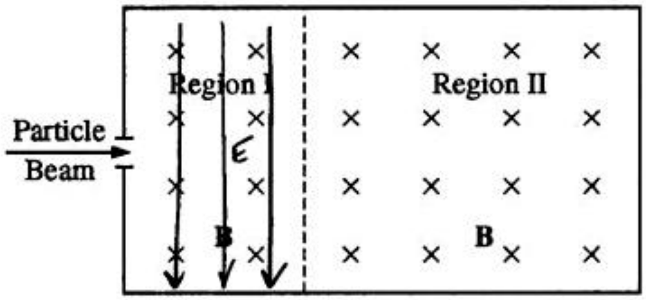
Justify your answer.

(d) A particle of the same mass and the same speed as in (a)ii but with charge $q = -3.2 \times 10^{-19}$ C enters region I. On the following diagram, sketch the complete resulting path of the particle.



(a)

(i) 2 points



For at least two correct electric field lines in the right directions 1 point
For the lines going through the entire Region I from top to bottom 1 point
<u>Note:</u> A single line going from top to bottom could earn a maximum of 1 point.

(ii) 2 points

For either of the first two equations below 1 point

$$q\upsilon B = qE$$

$$\upsilon = E/B$$

$$\upsilon = (4800\ \text{N/C})/(0.12\ \text{T})$$

$$\upsilon = 4.0 \times 10^4\ \text{m/s}$$

For the correct answer with units 1 point

(b) 2 points

$$q\upsilon B = \frac{m\upsilon^2}{r}$$

For the correct equation for the radius 1 point

$$r = \frac{m\upsilon}{qB}$$

For correct substitutions consistent with the answer to (a)(ii) 1 point

$$r = \frac{\left(6.68 \times 10^{-26}\ \text{kg}\right)\left(4.0 \times 10^4\ \text{m/s}\right)}{\left(3.2 \times 10^{-19}\ \text{C}\right)(0.12\ \text{T})}$$

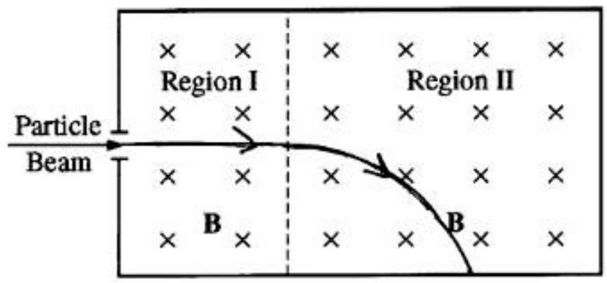
$$r = 0.070\ \text{m}$$

(c) 2 points

For indicating that the initial force is "Toward the bottom of the page" 1 point

For a correct justification indicating that the magnetic force ($F_B = qvB$) decreases as velocity decreases, while the electric force ($F_E = qE$) remains the same, so $F_E > F_B$. 1 point

(d) 2 points



For the path in Region I being straight and horizontal 1 point

For the path in Region II being a circular arc, curving downward 1 point

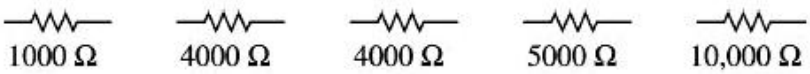
5) (15 points)
A student is asked to design a circuit to supply an electric motor with 1.0 mA of current at 3.0 V potential difference.

(a) Determine the power to be supplied to the motor.

(b) Determine the electrical energy to be supplied to the motor in 60 s.

(c) Operating as designed above, the motor can lift a 0.012 kg mass a distance of 1.0 m in 60 s at constant velocity. Determine the efficiency of the motor.

To operate the motor, the student has available only a 9.0 V battery to use as the power source and the following five resistors.



(d) In the space below, complete a schematic diagram of a circuit that shows how one or more of these resistors can be connected to the battery and motor so that 1.0 mA of current and 3.0 V of potential difference are supplied to the motor. Be sure to label each resistor in the circuit with the correct value of its resistance.

(a) 3 points

For correct equation for power — 1 point

$P = IV$

For the correct answer — 2 points

$P = 3$ mW (or 0.003 W)

One point was subtracted for incorrect or missing unit

(b) 3 points

For the correct equation for work or energy — 1 point

W (or energy) $= Pt$

For correct substitution of power from part (a) — 1 point

W (or energy) = (0.003 W)(60 s)

For the correct answer consistent with substitution of power from part (a), with correct units — 1 point

W (or energy) = 0.180 J

(c) 5 points

For the correct efficiency equation — 1 point

$$\text{efficiency} = \frac{W_o}{W_i}$$

For correct substitution of W_i (work done in 60 s) from part (b) — 1 point

For indicating that the work output W_o equals the change in gravitational potential energy — 1 point

$W_o = mg\,\Delta h$

For correct calculation of work output in 60 s — 1 point

$W_o = (0.012\text{ kg})(9.8\text{ m/s}^2)(1\text{ m}) = 0.12\text{ J}$ (or same answer using $g = 10\text{ m/s}^2$)

For correct calculation of efficiency consistent with calculation made in part (b). — 1 point

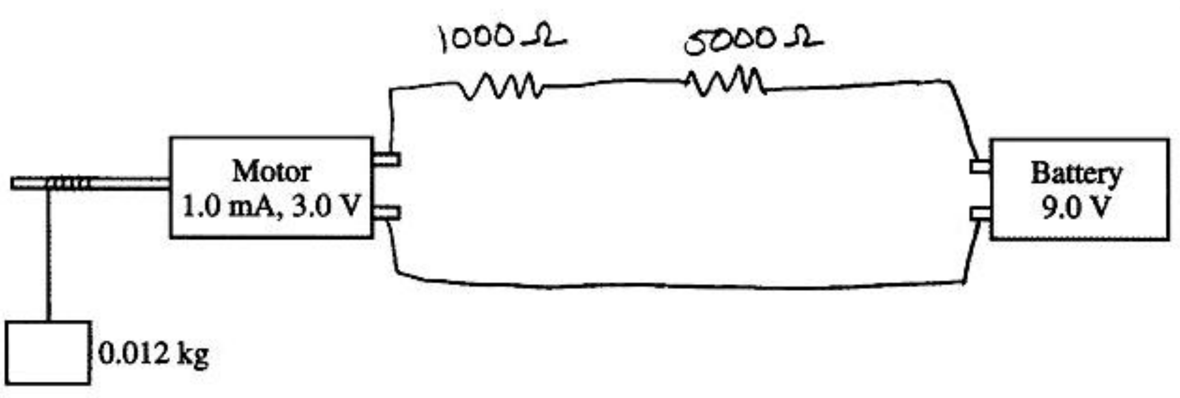
$$\text{efficiency} = \frac{0.12\text{ J}}{0.18\text{ J}} = 66.7\%$$ (or 65.3% using $g = 9.8\text{ m/s}^2$ and unrounded value for W_o)

Alternately, full credit could also be obtained by calculating efficiency using the ratio of power output to power input, in which case

$$\text{eff} = \frac{P_o}{P_i} = \frac{(0.012\text{ kg})(9.8\text{ m/s}^2)(1\text{ m})/60\text{ s}}{0.003\text{ W}} = 65.3\%$$ (or 66.7% using $g = 10\text{ m/s}^2$)

Similar point allocations were assigned using this method.

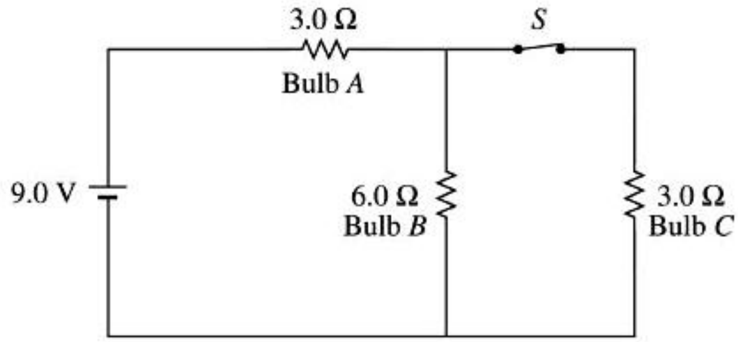
(d) 4 points



For a calculation or notation that 6 V was the voltage drop across the resistor needed in order to reduce the voltage across the motor from 9 V to 3 V.	1 point

Series resistance needed to produce this voltage drop $= \dfrac{6.0\text{ V}}{1.0\text{ mA}} = 6000\ \Omega$

For the selection of a 1000 Ω and a 5000 Ω resistor	1 point
For the placement of the 1000 Ω and 5000 Ω resistor in series	1 point
For an appropriate sketch of the system with appropriate symbols and labels for resistors	1 point



6) (15 points)

Lightbulbs of fixed resistance 3.0 Ω and 6.0 Ω, a 9.0 V battery, and a switch S are connected as shown in the schematic diagram above. The switch S is closed.

(a) Calculate the current in bulb A.

(b) Which lightbulb is brightest? Justify your answer.

(c) Switch S is then opened. By checking the appropriate spaces below, indicate whether the brightness of each lightbulb increases, decreases, or remains the same. Explain your reasoning for each lightbulb.

i. Bulb A: The brightness ___ increases ___ decreases ___ remains the same

Explanation:

ii. Bulb B: The brightness ___ increases ___ decreases ___ remains the same

Explanation:

iii. Bulb C: The brightness ___ increases ___ decreases ___ remains the same

Explanation:

(a) 6 points

For the correct expression for the total resistance in the parallel branch — 1 point

$$\frac{1}{R_p} = \frac{1}{6\ \Omega} + \frac{1}{3\ \Omega}$$

For the correct value for the parallel branch — 1 point

$R_p = 2\ \Omega$

For correctly combining R_p in series with the remaining resistance — 1 point

$R_t = 2\ \Omega + 3\ \Omega$

For the correct total resistance — 1 point

$R_t = 5\ \Omega$

For using Ohm's law — 1 point

$I = V/R = 9\ \text{V}/5\ \Omega$

For the correct answer — 1 point

$I = 1.8\ \text{A}$

(b) 3 points

For indicating that bulb A is brightest — 1 point

For a correct justification based on the power expended by each bulb (either quantitative reasoning or direct calculations) — 2 points

For example:

$P = I^2 R$

$P_A = (1.8\ \text{A})^2 (3\ \Omega) = 9.7\ \text{W}$

One third of the current flows through bulb B and two-thirds through bulb C

$$P_B = \left(\frac{1.8\ \text{A}}{3}\right)^2 (6\ \Omega) = 2.2\ \text{W} \quad \text{and} \quad P_C = \left(\frac{2(1.8\ \text{A})}{3}\right)^2 (3\ \Omega) = 4.3\ \text{W}$$

One justification point was awarded for only discussing the relative currents in the bulbs or the relative voltages across them.

(c)

i. 2 points

For indicating that the brightness of bulb A decreases — 1 point

For a correct justification — 1 point

For example: The total resistance increases so the current through bulb A decreases, thus decreasing its power output

ii. 2 points

For indicating that the brightness of bulb B increases — 1 point

For a correct justification — 1 point

For example: The current through bulb B increases, thus increasing its power output

iii. 2 points

For indicating that the brightness of bulb C decreases — 1 point

For a correct justification — 1 point

For example: The current through bulb C is now zero, so the bulb goes out

7) (15 points)

Two lightbulbs, one rated 30 W at 120 V and another rated 40 W at 120 V, are arranged in two different circuits.

(a) The two bulbs are first connected in parallel to a 120 V source.

i. Determine the resistance of the bulb rated 30 W and the current in it when it is connected in this circuit.

ii. Determine the resistance of the bulb rated 40 W and the current in it when it is connected in this circuit.

(b) The bulbs are now connected in series with each other and a 120 V source.

i. Determine the resistance of the bulb rated 30 W and the current in it when it is connected in this circuit.

ii. Determine the resistance of the bulb rated 40 W and the current in it when it is connected in this circuit.

(c) In the spaces below, number the bulbs in each situation described, in order of their brightness. (1 = brightest, 4 = dimmest)

____30 W bulb in the parallel circuit

____40 W bulb in the parallel circuit

____30 W bulb in the series circuit

____40 W bulb in the series circuit

(d) Calculate the total power dissipated by the two bulbs in each of the following cases.

i. The parallel circuit

ii. The series circuit

(a) i. 3 points

For both a correct power formula and Ohm's law, either shown explicitly or applied — 1 point
For a correct calculation of resistance — 1 point
For a correct calculation of current — 1 point
This point was awarded if an incorrect value for resistance was correctly used with 120 V.
The calculations can be done in slightly different ways and in different orders.
One example follows:

$$P = IV \text{ and } I = \frac{V}{R}\text{, so } P = \frac{V^2}{R}$$

$$R = \frac{V^2}{P} = \frac{(120\ \text{V})^2}{30\ \text{W}} = 480\ \Omega$$

$$I = \frac{V}{R} = \frac{120\ \text{V}}{480\ \Omega} = 0.25\ \text{A}$$

(a) ii. 2 points

For a correct calculation of resistance — 1 point
For a correct calculation of current — 1 point
This point was awarded if an incorrect value for resistance was correctly used with 120 V.
Again, the calculations can be done in slightly different ways and in different orders.
One example follows:

$$R = \frac{V^2}{P} = \frac{(120\ \text{V})^2}{40\ \text{W}} = 360\ \Omega$$

$$I = \frac{V}{R} = \frac{120\ \text{V}}{360\ \Omega} = 0.33\ \text{A}$$

(b) i. and ii. 4 points

These two parts were scored as a unit.
For showing by calculation or by statement that the resistance in part (b)i is assumed to be the same as in part (a)i, and the resistance in part (b)ii is assumed to be the same as in part (a)ii — 1 point
This point could also be awarded to students who recognized the bulbs as non-ohmic and stated this clearly, specifying lower resistances to be used in the solution.

$R_{\text{"30"}} = 480\ \Omega$

$R_{\text{"40"}} = 360\ \Omega$

(b) i. and ii. continued

For adding both resistances to calculate the total series resistance R_{tot} used in the Ohm's law calculation of current — 1 point

$R_{tot} = 480\ \Omega + 360\ \Omega = 840\ \Omega$

For calculating the correct current in part (b)i, or for a current consistent with the total resistance calculated — 1 point

$$I_{"30"} = I_{tot} = \frac{V}{R_{tot}} = \frac{120\ \text{V}}{840\ \Omega} = 0.14\ \text{A}$$

For stating that the current in part (b)ii is the same as in part (b)i, whether or not the (b)i current is correct — 1 point

$I_{"40"} = I_{"30"} = I_{tot} = 0.14\ \text{A}$

(c) 3 points

__2__30 W bulb in the parallel circuit

__1__40 W bulb in the parallel circuit

__3__30 W bulb in the series circuit

__4__40 W bulb in the series circuit

For any order showing that both bulbs in parallel are brighter than both in series — 1 point

For any order showing the 40 W bulb in the parallel circuit is brighter than the 30 W bulb in the parallel circuit — 1 point

For any order showing the "30 W" bulb in the series circuit is brighter than the "40 W" bulb in the series circuit — 1 point

(d) i. 1 point

For a correct answer or calculation consistent with values reported in part (a) — 1 point

$P_{tot} = 30\ \text{W} + 40\ \text{W} = 70\text{W}$

OR $P_{tot} = \dfrac{V^2}{R_{tot}} = \dfrac{(120\ \text{V})^2}{206\ \Omega} = 70\ \text{W}$

OR $P_{tot} = \sum VI = (120\ \text{V})(0.25\ \text{A}) + (120\ \text{V})(0.33\ \text{A}) = 70\ \text{W}$

(d) ii. 2 points

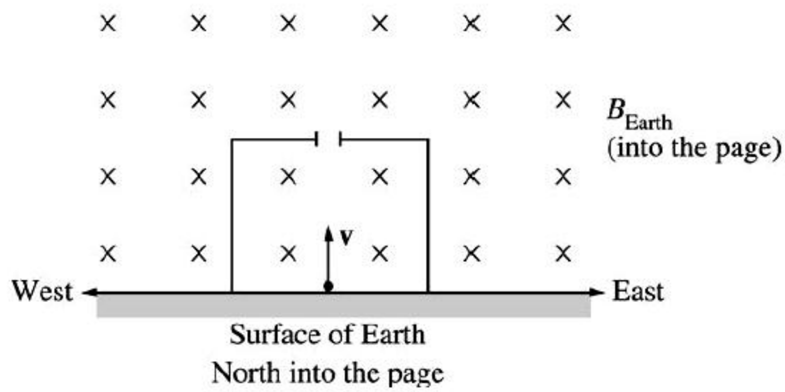
For using values from part (b) correctly in the equations 1 point
For correct answer or calculation consistent with values reported in part (b) 1 point

$$P_{tot} = \frac{V^2}{R_{tot}} = \frac{(120\ \text{V})^2}{840\ \Omega} = 17\ \text{W}$$

OR $P_{tot} = \sum I^2 R = (0.14\ \text{A})^2 (480\ \Omega) + (0.14\ \text{A})^2 (360\ \Omega) = 17\ \text{W}$

OR $P_{tot} = VI = (120\ \text{V})(0.14\ \text{A}) = 17\ \text{W}$

Note: Both points were awarded for the correct answer, 17 W, as long as it was consistent with the work in part (b). No points were awarded for answers of 70 W unless student's work clearly showed that it was obtained using a combination of values for R, V, and I consistent with part (b).



8) (10 points)

A proton of mass m_p and charge e is in a box that contains an electric field E, and the box is located in Earth's magnetic field B_{Earth}. The proton moves with an initial velocity **v** vertically upward from the surface of Earth. Assume gravity is negligible.

(a) On the diagram above, indicate the direction of the electric field inside the box so that there is no change in the trajectory of the proton while it moves upward in the box. Explain your reasoning.

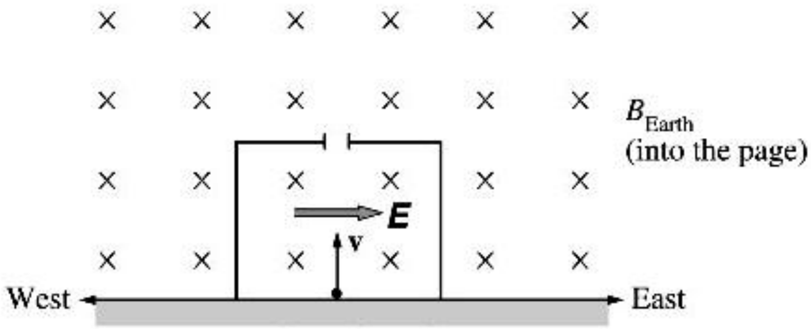
(b) Determine the speed of the proton while in the box if it continues to move vertically upward. Express your answer in terms of the fields and the given quantities.

The proton now exits the box through the opening at the top.

(c) On the figure on the previous page, sketch the path of the proton after it leaves the box.

(d) Determine the magnitude of the acceleration a of the proton just after it leaves the box, in terms of the given quantities and fundamental constants.

(a) 3 points



For drawing the electric field vector to the right (labeled as E or unlabeled) and parallel to the base of the box — 1 point

For demonstrating an understanding of the physics involved in balancing the magnetic <u>force</u> with an electric <u>force</u>, and for demonstrating an understanding that the electric force and electric field are in the same direction for a proton — 2 points

<u>Note</u>: It was possible to misapply the right-hand rule and obtain an electric field vector to the left, thus not receiving the first point, but still receive 1 or 2 points for the explanation if it was consistent with this direction of the electric field vector.

(b) 2 points

For indicating that the magnetic force and electric force are equal in magnitude, $F_B = F_E$, and thus $evB_{Earth}\sin\theta = eE$ — 1 point

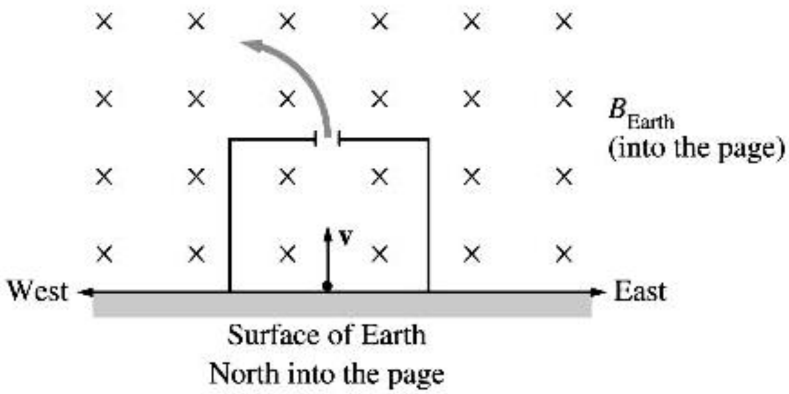
The velocity and magnetic field are perpendicular to each other, i.e. $\theta = 90°$, so $\sin\theta = 1$

For the correct solution of the above equation for speed in terms of the fields — 1 point

$$v = \frac{E}{B_{Earth}}$$

<u>Note</u>: Since the question asked for the speed "in terms of the fields and the given quantities", and since v was unintentionally a given quantity, 2 points were also awarded for realizing that the forces balance and thus the speed remains the same as its initial value, the magnitude of v.

(c) 2 points



For sketching a path that moves to the west (i.e. to the left)	1 point
For having the path start out concave downward (either west or east) as soon as the proton leaves the box, and continuing that way for a short distance	1 point

(d) 3 points

For realizing that there is a single force accelerating the proton and that Newton's 2nd law applies — 1 point

$F = m_p a$

For knowing that the force is magnetic and substituting its value into Newton's 2nd law — 1 point

$evB_{Earth} = m_p a$

For solving for a correctly — 1 point

$a = \dfrac{evB_{Earth}}{m_p}$

Note: By substituting $v = \dfrac{E}{B_{Earth}}$ from part (b), the final answer may be expressed as $a = \dfrac{eE}{m_p}$, because those are also given quantities, but full credit was awarded only if it was clearly shown that the force accelerating the proton is the magnetic force.

(d) continued

Alternate Solution	*Alternate points*

There were several variations of an alternate solution all involving the use of the idea that a particle in a magnetic field with velocity perpendicular to the field will move in a circle of radius r at constant speed, and with centripetal acceleration $a = \frac{v^2}{r}$.

The following is one example.

For realizing that the force accelerating the proton is centripetal — *1 point*

$$F = m_p a = \frac{m_p v^2}{r}$$

For knowing that the force is magnetic and substituting its value into the equation above — *1 point*

$$evB_{Earth} = \frac{m_p v^2}{r}$$

Solving for r:

$$r = \frac{m_p v}{eB_{Earth}}$$

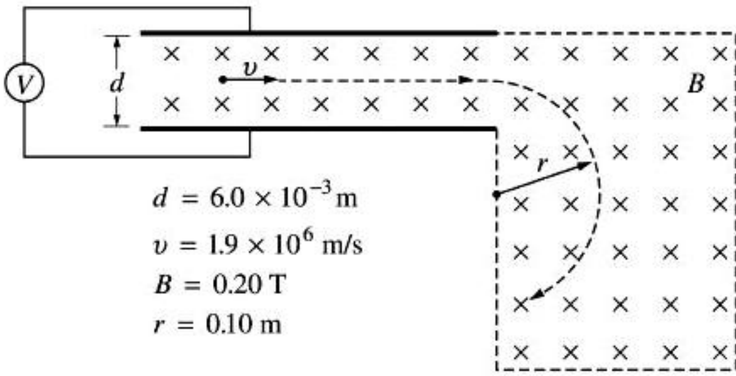
Substituting this value of r into the equation $a = \frac{v^2}{r}$:

$$a = \frac{v^2}{\left(\frac{m_p v}{eB_{earth}}\right)}$$

For correct answer — *1 point*

$$a = \frac{evB_{Earth}}{m_p}$$

Note: Other variations of this general approach could also receive full credit if correct



9) (10 points)

A particle with unknown mass and charge moves with constant speed $v = 1.9 \times 10^6$ m/s as it passes undeflected through a pair of parallel plates, as shown above. The plates are separated by a distance $d = 6.0 \times 10^{-3}$ m, and a constant potential difference V is maintained between them. A uniform magnetic field of magnitude $B = 0.20$ T directed into the page exists both between the plates and in a region to the right of them as shown. After the particle passes into the region to the right of the plates where only the magnetic field exists, its trajectory is circular with radius $r = 0.10$ m.

(a) What is the sign of the charge of the particle? Check the appropriate space below.

__ Positive __ Negative __ Neutral __ It cannot be determined from this information.

Justify your answer.

(b) On the diagram above, clearly indicate the direction of the electric field between the plates.

(c) Determine the magnitude of the potential difference V between the plates.

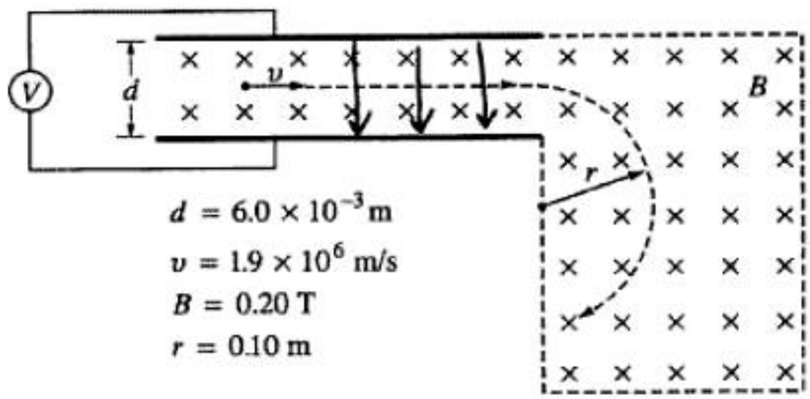
(d) Determine the ratio of the charge to the mass (q/m) of the particle.

(a) 2 points

For indicating that the particle has a negative charge | 1 point
For a reasonable justification that considers the particle's behavior in the region of magnetic field outside the space between the plates. | 1 point

For example: By the right-hand rule, the directions of the velocity and the magnetic field indicate that a positive charge would move in a circular path curving above the plates. Since the curve is in the opposite direction the charge must be negative.

(b) 2 points



For indicating a vertical field only in the region between the plates, and not extending outside that region — 1 point

For indicating that the field is downward — 1 point

(c) 3 points

For a correct relationship between the potential difference and the electric field — 1 point

$E = V/d$

Between the plates, the electric and magnetic forces must be equal in order for the particle to pass through undeflected

For a correct expression relating the electric and magnetic fields — 1 point

$qE = qvB$

Substituting for the electric field and solving for the potential:

$V = vBd$

$V = (1.9 \times 10^{6}\ \text{m/s})(0.20\ \text{T})(6 \times 10^{-3}\ \text{m})$

For the correct answer — 1 point

$V = 2300$ V

(d) 3 points

For correctly relating the centripetal and magnetic forces on the particle — 1 point

$$\frac{mv^2}{r} = qvB$$

For the correct expression for $\frac{q}{m}$ — 1 point

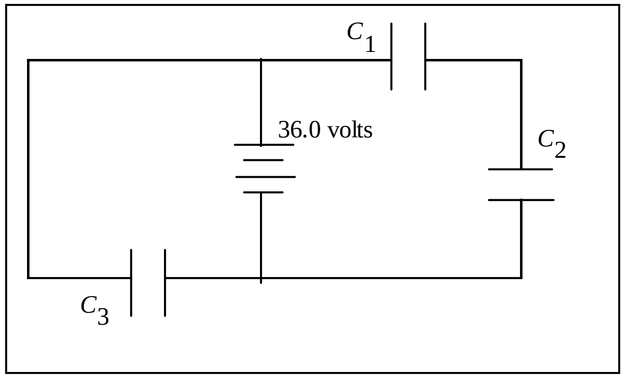
$$\frac{q}{m} = \frac{v}{rB}$$

$$\frac{q}{m} = \frac{1.9 \times 10^6 \text{ m/s}}{(0.10 \text{ m})(0.20 \text{ T})}$$

For a correct answer — 1 point

$$\frac{q}{m} = 9.5 \times 10^7 \text{ C/kg}$$

10) Three capacitors (C_1 = 22 μF, C_2 = 33 μF and C_3 = 15 μF) are connected as shown to a 36.0 volt battery. The arrangement has been connected for a long time and is in equilibrium. **(13points)**



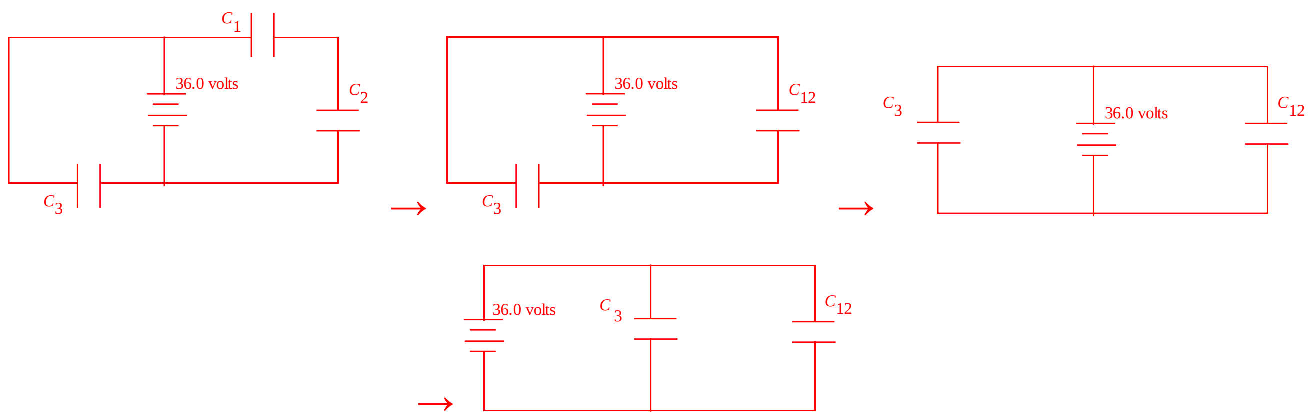
(a) Calculate the equivalent (total) capacitance of the network shown. **(3 points)**

(b) Calculate the charge (in microCoulombs) on capacitor C_3 . **(3 points)**

(c) Calculate the potential difference (voltage) across capacitor C_1. **(4 points)**

(d) Calculate the total amount of energy (in milliJoules) stored in all the capacitors of this arrangement. **(3 points)**

(a) First, reduce the circuit to see what is happening more easily;



Above, C_{12} is; $\frac{1}{C_{12}} = \frac{1}{C_1} + \frac{1}{C_2} \rightarrow \frac{1}{C_{12}} = \frac{1}{22} + \frac{1}{33} \rightarrow C_{12} = 13.2\ \mu\text{F}$

Thus, C_{tot} is just C_{12} and C_3 in parallel, which becomes; $C_{tot} = 13.2\ \mu\text{F} + 15\mu\text{F} \rightarrow \boxed{C_{tot} = 28.2\ \mu\text{F}}$

(1 point for correctly determining the voltage on C_3 via parallel connection)
(1 point for correctly using $Q = CV$ for calculating Q_3)
(1 point for correct calculation of answer with correct unit)

Therefore, to find the charge Q_3, it is necessary to realize that C_3 and C_{12} are in parallel with the battery, and thus each has the battery voltage (parallel capacitors). Thus, V_3 = 36 volts, and from $Q = CV$, the charge Q_3 may be found;

$$Q_3 = C_3 V_3 \rightarrow Q_3 = (15\ \mu\text{F})(36\ \text{volts}) \rightarrow \boxed{\boldsymbol{Q_3 = 540\ \mu\text{C}}}$$

(1 point for correctly determining the voltage on C_3 via parallel connection)
(1 point for correctly using $Q = CV$ for calculating Q_3)
(1 point for correct calculation of answer with correct unit)

(b) Note that C_1 and C_2 are in series and thus have equal charge on their plates. Thus, find Q_{12} and then use that Q_{12} as Q_1 to get V_1;

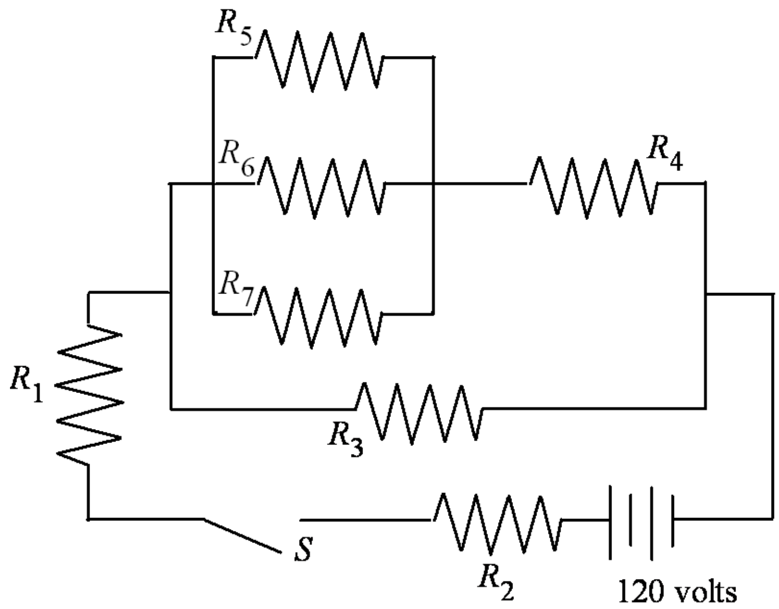
$$Q_{12} = C_{12}V_{12} \rightarrow Q_{12} = (13.2\ \mu\text{F})(36\ \text{volts}) \rightarrow \boxed{Q_{12} = 475.2\ \mu\text{C}}$$

Thus, $Q_1 = C_1V_1 \rightarrow \frac{Q_1}{C_1} = V_1 \rightarrow V_1 = \frac{475.2\ \mu\text{C}}{22\ \mu\text{F}} \rightarrow \boxed{\mathbf{V_1 = 21.6\ volts}}$

(1 point for correctly reducing C_1 and C_2 in series to determine V_{12})
(1 point for correctly calculating Q_{12} in order to determine Q_1 and Q_2 in series)
(1 point for correctly calculating V_1 using Q_{12})
(1 point for correct calculation of answer with correct unit)

(c) Total energy is $U_{tot} = \frac{1}{2}C_{tot}V_{tot}^2 \rightarrow \frac{1}{2}(28.2\ \mu\text{F})(36)^2 \rightarrow \boxed{\mathbf{U_{tot} = 18.3\ milliJoules}}$

(1 point for correctly determining the equivalent capacitance; see (a) above)
(1 point for correctly using the energy equation)
(1 point for correct calculation of answer with correct unit)



11) In the circuit shown above, seven resistors (R_1 through R_7) are connected in a complex circuit with a switch S and a 120 volt battery. The seven resistors have the following color code values; **(11 points)**

R_1 = yellow, violet, brown (470) R_2 = red, green, brown (250) R_3 = blue, yellow, brown (640)

R_4 = brown, black, brown (100) R_5 = violet, violet, brown (770) R_6 = red, green, black (25)

R_7 = brown, yellow, red (1400)

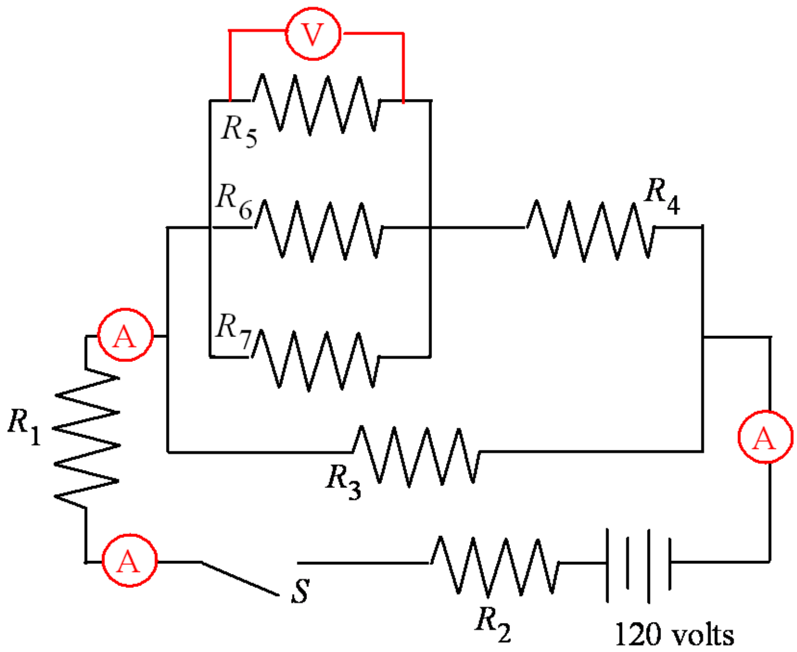
The switch is now closed.

(a) In the diagram above, draw an ammeter in the circuit to measure the total electric current. **(1 point)**

(b) Calculate the reading of the value (in milliamps) on the ammeter you drew in part (a). **(6 points)**

(c) In the diagram above, draw a voltmeter in the circuit to measure the voltage across the resistor combination R_5, R_6 and R_7. **(1 point)**

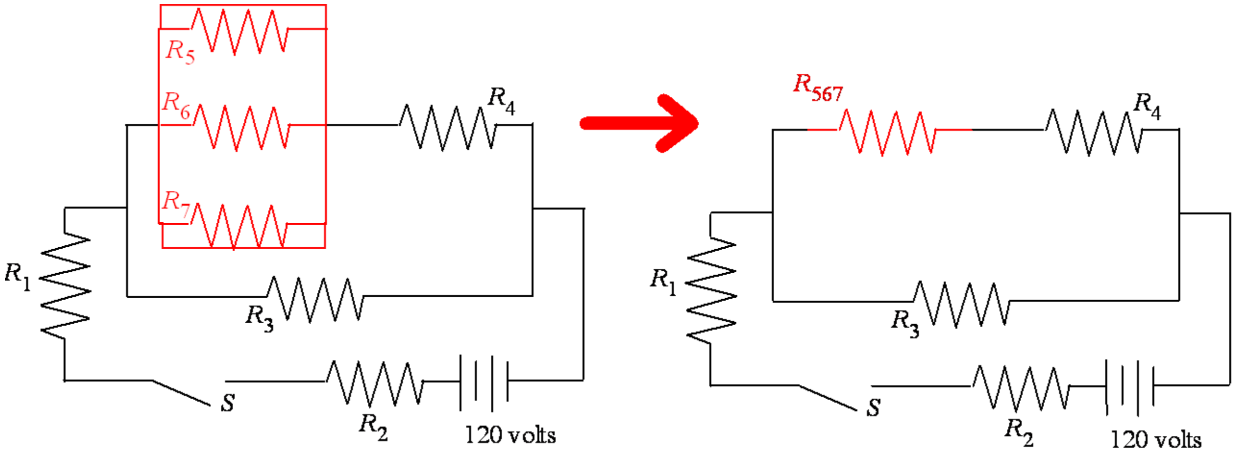
(d) Calculate the reading (in volts) of the value on the voltmeter you drew in part (c). **(3 points)**



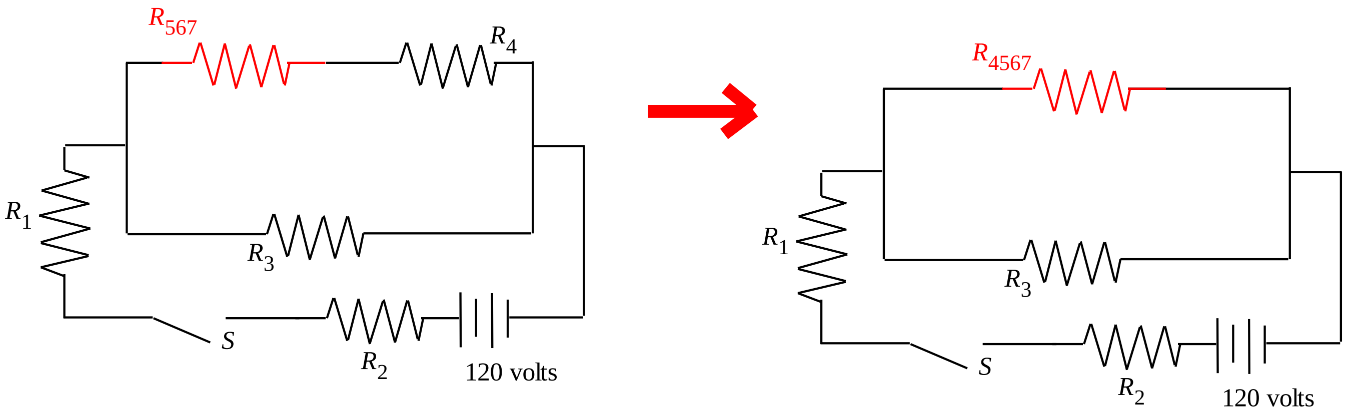
(a) Shown above (one of at least three locations). **(1 point for a correct location of an ammeter to measure I_{tot})**
(c) Shown above. **(1 point for a correct location of a voltmeter across the 5-6-7 parallel resistor group)**

(b) You need the total current, which is the value on the ammeter "A" which is found by reducing the entire circuit to one simple series circuit.

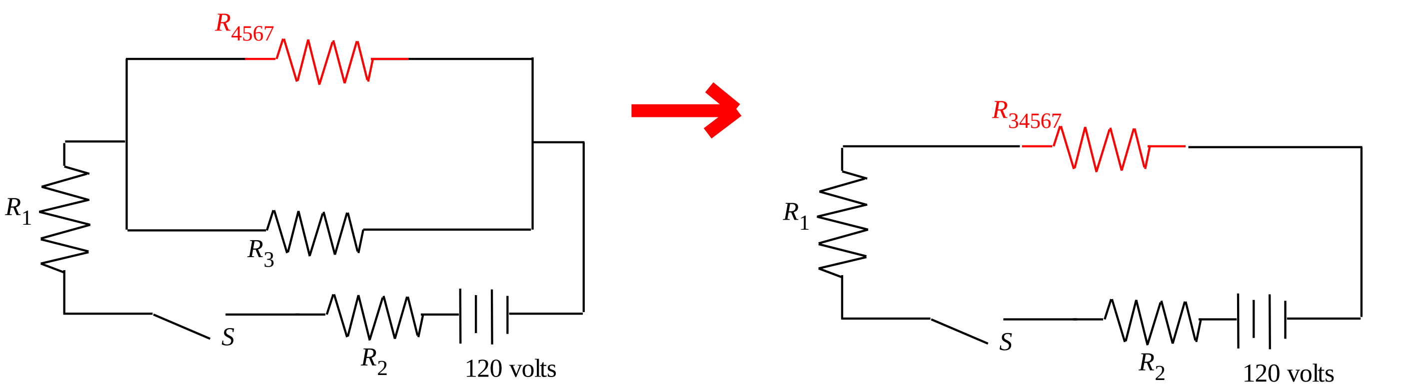
$V = IR \rightarrow I_{tot} = \frac{V_{tot}}{R_{tot}}$ Therefore, you must reduce the circuit to one large resistor and thus find the total resistance as shown below;



$$\frac{1}{R_{567}} = \frac{1}{R_5} + \frac{1}{R_6} + \frac{1}{R_6} \rightarrow \boxed{R_{567} = 23.8\ \Omega}$$ (above)



$$R_{4567} = 23.8 + 100 \quad \rightarrow \quad \boxed{R_{4567} = 123.8\ \Omega}$$ (above)



$$\frac{1}{R_{34567}} = \frac{1}{R_{4567}} + \frac{1}{R_3} \quad \rightarrow \quad \frac{1}{R_{34567}} = \frac{1}{123.8} + \frac{1}{640} \quad \rightarrow \quad \boxed{R_{34567} = 103.7\ \Omega}$$ (above)

Therefore, the final total resistance is just R_{34567} in series with R_2; $\rightarrow$ $\boxed{\boldsymbol{R_{tot} = 823.7\ \Omega}}$

$$\rightarrow I_{tot} = \frac{V_{tot}}{R_{tot}} = \frac{120}{823.7} \rightarrow \boxed{\boldsymbol{I_{tot} = 145.7\ \text{mA}}}$$

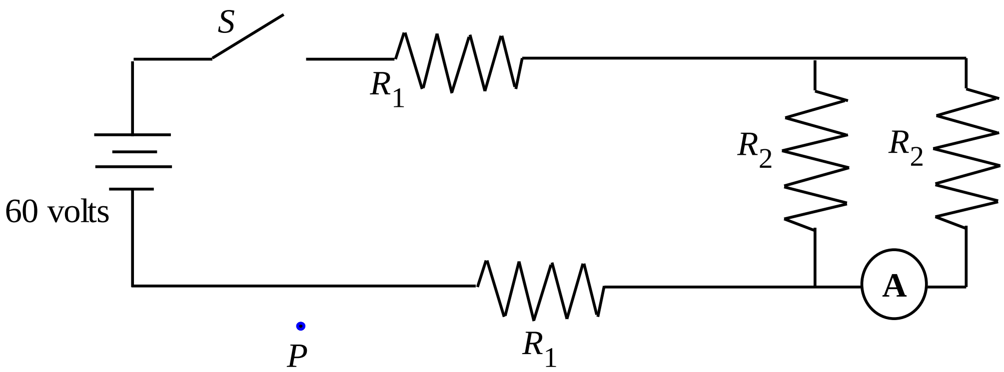
(1 point for reducing resistors 567 in parallel)
(1 point for reducing resistors 4 & 567 in series)
(1 point for reducing resistors 3 & 4567 in parallel)
(1 point for reducing resistors 2 & 34567 in series as the final reduction)
(1 point for correctly using the total resistance in Ohm's Law)
(1 point for correct answer for the total current WITH correct mA conversion)

(d) $I_{567} \rightarrow V_{103} = I_{103}R_{103}$ → (145.7 mA)(103.7 ohms) = 15.1 volts = V_{103}

$$I_{23} = I_{100} \rightarrow I_{123} = \frac{V_{123}}{123\ ohms} = \frac{15.1\ volts}{123\ ohms} \rightarrow I_{123} = 122.1\ \text{mA}$$

$V_{23.8} = I_{23.8}R_{23.8}$ → (122.1 mA)(23.8 ohms) → $\boxed{\mathbf{V_{23.8} = 2.9\ volts}}$

(1 point for correctly determining V across the 103 ohm group)
(1 point for correctly calculating the current in the 123.8 ohm group)
(1 point for correctly calculating the final voltage across the 23.8 ohm group)



12) In the circuit shown above, long wires, a battery and four resistors (R_1 and R_2, occurring twice each) are all connected with a switch S. The resistors have the following color code values; **(12 points)**

R_1 = brown, black, brown (100) R_2 = red, black, brown (200)

The switch is now closed. Assume that any magnetic fields in this problem arise only from the currents in the wires.

(a) Determine the equivalent (total) resistance of this circuit. **(4 points)**

(b) What is the numerical reading of the ammeter shown, placed in the circuit between the both resistors labelled R_2? **(3 points)**

(c) Of the options shown below, place a check next to the one which correctly states the direction of the *net* magnetic field at point P.

_____ To the left _____ Toward the top of the page _____ Out of the page

_____ To the right _____ Toward the bottom of the page _____ Into the page

_____ There is no magnetic field at point P.

Explain your reasoning. **(3 points)**

(d) What is amount of energy consumed by the circuit in 15 minutes? **(2 points)**

(a) R_1 = brown, black, brown **(100 ohms)** R_2 = red, black, brown **(200 ohms)**

Both resistors R_2 are in parallel, and then when summed, they are both in series with the two resistors R_1;

$$R_{tot} = 100 + 100 + \left[\left(\frac{1}{200} + \frac{1}{200}\right)\right]^{-1} \rightarrow \text{Therefore, } \boxed{R_{tot} = 300 \text{ ohms} = 3.0 \times 10^2 \text{ ohms}}$$

(1 point for determining the value of each resistor using the color code chart)
(1 point for realizing/determining the total resistance of both R_2 values in parallel)
(1 point for realizing/determining that both R_1 values are connected in series with the total of R_2)
(1 point for correctly determining the total resistance of the circuit with correct unit)

(b) First it is necessary to find the voltage across the two parallel resistors, so they need to be reduced and treated as one series resistor with the rest, then the voltage on that series resistor is the voltage across each of the two parallel ones (because they are in parallel). Thus, by Ohm's law;

$$I_{tot} = \frac{V_{tot}}{R_{tot}} \rightarrow = \frac{60}{300} \quad \text{Thus, } \boxed{I_{tot} = 0.2 \text{ A}}$$

The voltage across each R_1 resistor is then;

$$V_1 = I_1 R_1 \rightarrow V_1 = (0.2)(100) \rightarrow \boxed{V_1 = 20 \text{ volts}}$$

Since there are two resistors of 100 ohm value, each must get 20 volts, therefore leaving 20 volts to show up across the parallel branch (since the total must be 60 volts). Thus, each R_2 resistor has 20 volts across it. From this, we can find each R_2 current;

$$I_2 = \frac{20}{200} \rightarrow \boxed{I_2 = 0.1 \text{ A}}$$

Therefore, the ammeter reading is $\boxed{I_2 = 0.1 \text{ Amp}}$

(1 point for determining the value the total current in the circuit)
(1 point for realizing/determining the voltage across the parallel grouping is 20 volts)
(1 point for realizing/determining the value of the current in R_2, the reading on the ammeter)

(c) _____ To the left　　_____ Toward the top of the page　　**X** Out of the page

_____ To the right　　_____ Toward the bottom of the page　　_____ Into the page

_____ There is no magnetic field at point *P*.

Current in the circuit is clockwise and the magnetic field at *P* is due BOTH to the top wire (where R_1 is) and to the bottom wire (where the second R_1 is). At point *P*, the top wire has a magnetic field that is pointed into the page however the lower wire gives a magnetic field that is out of the page (both by RHR). Since point *P* is much closer to the bottom wire, that wire's field is dominant, and thus, the net field must point out of the page.

(1 point for correct box checked stating "out of the page")
(1 point for correctly determining the field directions from both top and bottom wires)
(1 point for correctly determining the direction of the net field due to the dominance of the bottom wire)

(d) $E = P\Delta t \quad \rightarrow E = (I_{tot}^2 R_{tot})\Delta t = \ (0.2)^2(300)(15 \text{ min } x \frac{60 \text{ sec}}{\text{min}})$

$\rightarrow$ Therefore, $\boxed{\boldsymbol{E_{tot} = 1.1 \text{ x } 10^4 \text{ Joules}}}$

(1 point for determining the total power in the circuit AND correctly converting time to seconds)
(1 point for the correct answer with correct unit)