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Tutorial Questions

Contents

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1 Chapter 1: Electrostatics

Coulomb's Law

1. Calculate the Coulomb force between a charged particle of $2\mu C$ and another particle of $5\mu C$. Is it repulsive or attractive? Sketch the situation described and label the Coulomb forces on each particle.

2. Three point charges are placed at the following points on the x-axis: $+2\mu C$ at $x = 0$, $-3\mu C$ at $x = 40cm$, $-5\mu C$ at $x = 120cm$. Find the force on the $-3\mu C$ charge.

3. Consider two charges of $4\mu C$ and $3\mu C$ that are placed such that the separation between them is $1m$. Where, between the two aforementioned charges, should a third charge of $-2\mu C$ be placed so that it experiences zero net Coulomb force.

4. Three charges are placed on the vertices of an equiliateral triangle with sides 2m. If the charges are $2\mu C$, $-2\mu C$ and $3\mu C$, calculate the net force (and its direction) on a test charge if the test charge is placed in the middle of the triangle.

5. Four point charges are placed on the corners of a square that is $25cm$ on its side. The charge on the top right is $3\mu C$, the top left, $-2\mu C$, bottom left, $1.5\mu C$ and the charge on the bottom right to be $-2\mu C$. Calculate the net force exerted on the $-2\mu C$ by the three other charges.

Electric Field

1. Calculate the electric field at a distance of $0.2m$ from a charge of $3nC$.

2. A point charge of $2\mu C$ is placed at the origin of coordinates. Calculate the electric field at $(x, y) = (3, 4)m$.

3. Point charges $2\mu C$, $-5\mu C$ and $+8\mu C$ are placed at coordinates $(-1, 2)cm$, $(2, 2)cm$ and $(1.5, -3)cm$ respectively. Calculate the electric field at the origin. Calculate the force exerted on a charge of $0.5\mu C$ if it were to be placed on the origin.

4. Four point charges are placed on the corners of a square that is $20cm$ on its side. The charge on the top right is $3\mu C$, the top left, $-2\mu C$, bottom left, $1.5\mu C$ and the charge on the bottom right to be $-2\mu C$. Calculate the net electric field at the centre of the square.

5. *Three parts:

   (a) Consider two particles of charges $2\mu C$ and $-2\mu C$ placed on coordinates $(0, -1)m$ and $(0, 1)m$ respectively. Calculate the electric field at coordinate $(5, 0)m$ and $(20, 0)m$.

   (b) Now consider if instead we placed a single $4\mu C$ at the origin, calculate the electric field at coordinate $(5, 0)m$ and $(20, 0)m$.

   (c) Compare the numerical values for part (a) and (b). Comment on your results.

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Electrical Potential

1. What is the electric potential at $0.5m$ from a $40\mu C$ point charge?
2. The work done in bringing a charge of $20\mu C$ from infinity to a point in an area of electric field is $3 \times 10^4 J$. What is the electric potential at that point?
3. A hollow sphere has a radius of $2cm$ and contains a charge of $5\mu C$. Assuming this sphere to be isolated, calculate the potential at a distance of $75cm$ from the centre of the sphere.
4. Three equal point charges of $3\mu C$ are placed at three corners of a square of sides $20cm$. Find the electrical potential at the fourth corner of the square.
5. Two point charges X and Y of charge $3.5\mu C$ and $2\mu C$ respectively are placed $15cm$ from each other. Calculate the work done to move charge Y to $3cm$ nearer to charge X.

Charge in Uniform $\vec{E}$

1. 2 plate arrange parallel to each other are spaced $0.6cm$ apart. They are connected to a 90V battery. Find the electric field between them.
2. In the Milikan experiment, an oil drop carries 3 electronic charges and has a mass of $1.35 \times 10^{-12} g$. This oil drop is held at rest between two horizontal charged plates $1.8cm$ apart. What voltage must there be between the two charged plates to keep the oil drop at rest?
3. A proton is accelerated from rest through a potential difference of $1kV$. What is its final speed?
4. An electron moves from plate A (of electrical potential $-60V$) to plate B (of electrical potential $+50V$). Assuming the system is in vacuum, what is the speed of the electron just before it hits plate B?
5. An electron enters a region of electric field generated by two parallel plates of potential difference $150V$, with a plate separation of $50mm$. The length of the parallel plates is 65mm. If the electron enters the region with velocity $9 \times 10^6 ms^{-1}$, Calculate the
   (a) the acceleration of the electron in its vertical axis [Ans: $5.3 \times 10^{14} ms^{-2}$]
   (b) the time for which the electron travels through the region of electric field [Ans: $7.2 \times 10^{-9} s$]
   (c) the deviation of the electron upon exiting, from its original path [Ans: $1.37 \times 10^{-2} m$]
   (d) the velocity of the electron in its vertical axis as it exits the electric field [Ans: $3.8 \times 10^6 ms^{-1}$]

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2 Chapter 2: Capacitors

Capacitance in series and parallel

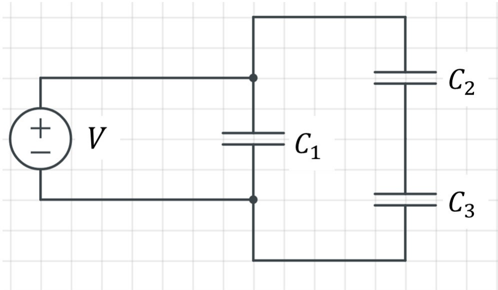
$\boxed{C = \frac{Q}{V};\, U = \frac{1}{2}QV}$

1. When the potential difference is $1kV$, the two plates of a capacitor hold $+4000\mu C$ and $-4000\mu C$ of charge respectively. What is the capacitance of this capacitor? Calculate the energy stored in the capacitor.

2. What is the voltage across a capacitor which has the capacitance of $12000\,pF$ and when fully charged, holds $24 \times 10^{-8}\,C$ of charge?

3. When the voltage across a capacitor is increased from $35V$ to $50V$, the charge of the capacitor was found to have increased from $30\mu C$ to $60\mu C$. Calculate the capacitance of the capacitor and the energy change.

4. In the figure below, suppose $C_i = \{10\mu, 12\mu, 8\mu\}F$.

   Calculate the equivalent capacitance of the circuit.

5. Referring to question 4, what would the voltage across each capacitor be if $C_i = \{2\mu, 3\mu, 4\mu\}F$ and $V = 26V$?

Capacitors Charging and Discharging

$\boxed{\tau = RC;\, Q = Q_o e^{-\frac{t}{RC}};\, Q = Q_o(1 - e^{-\frac{t}{RC}})}$

1. Calculate the time constant τ for an RC circuit with a $1k\Omega$ resistor and a $4000\mu F$ capacitor.

2. In the RC circuit, the capacitor initially has a charge of $20\mu C$. Calculate the charge in the capacitor after $8s$, if the time constant for the circuit is $4s$.

3. Calculate the time needed to charge capacitors the circuit below to 50% full.

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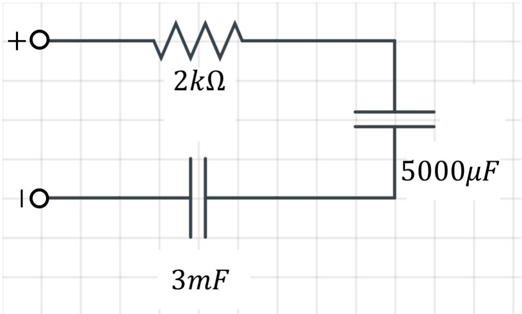

Capacitors with dielectrics

$\boxed{\varepsilon_r = \frac{\varepsilon}{\varepsilon_o};\ C_o = \frac{\varepsilon_o A}{d};\ C = \varepsilon_r C_o}$

1. What is the capacitance of a pair of circular plates with a radius of $2.5cm$ separated by $3mm$ of mica, that has a dielectric constant of 6.

2. A $4000pF$ air-gap capacitor is supplied with $24V$. Calculate the charge flow after a dielectric material of dielectric constant 3 is added between the plates.

Solutions:

Capacitance in series and parallel

$\boxed{C = \frac{Q}{V};\ U = \frac{1}{2}QV}$

1.

$$\begin{aligned} C &= \frac{Q}{V} \\ &= \frac{4000(10^{-6})\,C}{1000\,V} \\ &= 4\mu C \\ U &= \frac{1}{2}QV \\ &= \frac{1}{2}(4000\,\mu C)(1000\,V) \\ &= 2\,J \end{aligned}$$

2.

$$\begin{aligned} V &= \frac{Q}{C} \\ &= \frac{24(10^{-8})\,C}{12000(10^{-12})\,F} \\ &= 20V \end{aligned}$$

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3.

$$
\begin{aligned}
Q_i &= CV_i\,;\; Q_f = CV_f \\
\Delta Q &= Q_f - Q_i\,;\; \Delta V = V_f - V_i \\
\Delta Q &= C\Delta V \\
C &= \frac{\Delta Q}{\Delta V} \\
&= \frac{60\mu C - 30\mu C}{50V - 35V} \\
&= 2\mu F \\
\Delta U &= U_f - U_i \\
&= \frac{1}{2}(Q_f V_f - Q_i V_i) \\
&= \frac{1}{2}(50V(60\mu C) - 35V(30\mu C)) \\
&= 0.975mJ
\end{aligned}
$$

4. C_2 and C_3 in series

$$
C_{23} = \left(\frac{1}{C_2} + \frac{1}{C_3}\right)^{-1}
$$

C_{23} and C_1 are parallel to each other

$$
\begin{aligned}
C_{eq} &= C_1 + C_{23} \\
&= C_1 + \left(\frac{1}{C_2} + \frac{1}{C_3}\right)^{-1} \\
&= 10\mu + \left(\frac{1}{12\mu} + \frac{1}{8\mu}\right)^{-1} \\
&= 14.8\mu F
\end{aligned}
$$

5.

$$
\begin{aligned}
V_{total} &= V_1 = V_{23} = 26V \\
C_{23} &= \left(\frac{1}{C_2} + \frac{1}{C_3}\right)^{-1} \\
\text{Then for } j &= \{2, 3\}, \\
V_j &= \{\frac{Q_{23}}{C_2}, \frac{Q_{23}}{C_3}\} \\
&= \{\frac{C_{23}}{C_2}V_{23}, \frac{C_{23}}{C_3}V_{23}\} \\
&= \{14.85,\ 11.15\}V
\end{aligned}
$$

Capacitors Charging and Discharging

$\boxed{\tau = RC;\; Q = Q_o e^{-\frac{t}{RC}};\; Q = Q_o(1 - e^{-\frac{t}{RC}})}$

Tutorial Questions

1. $\tau = RC = (1000\Omega)(4000 \times 10^{-6}\,F) = 4s$
2. $Q = Q_o e^{-\frac{t}{\tau}} = (20\mu)e^{-\frac{8s}{4s}} = 2.71\mu C$
3.

$$\begin{aligned}
\tau &= RC_{eq} \\
&= (2000)\left(\frac{1}{0.003\,F} + \frac{1}{0.005\,F}\right)^{-1} \\
&= 3.75s \\
\text{50\% full:} \quad &\Rightarrow \frac{Q_f}{Q_o} = 0.5 \\
0.5\,Q_o &= Q_o(1 - e^{-\frac{t}{RC}}) \\
\frac{t}{RC} &\approx 0.69 \\
t &\approx 2.6s
\end{aligned}$$

Capacitors with dielectrics

$\boxed{\varepsilon_r = \frac{\varepsilon}{\varepsilon_o};\ C_o = \frac{\varepsilon_o A}{d};\ C = \varepsilon_r C_o}$

1.

$$\begin{aligned}
C = \varepsilon_r C_o &= \varepsilon_r \frac{\varepsilon_o A}{d} \\
&= 6\frac{(8.85 \times 10^{-12})(\pi(2.5 \times 10^{-2})^2)}{3 \times 10^{-3}} \\
&= 34.754pF
\end{aligned}$$

2.

$$\begin{aligned}
Q|_{\varepsilon_r=3} &= C_{with\,dielectric}V \\
&= \varepsilon_r C_o V \\
&= (3)(4000 \times 10^{-12})(24) \\
&= 0.288\mu F
\end{aligned}$$

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3 Chapter 3: DC circuits

Electric Conduction, Resistivity & Ohm's Law

1. A current of $8A$ is maintained in a conductor for $30s$. How much charge has flowed through the conductor in this time ?

2. Calculate the magnitude of current if 3×10^{23} electrons has flowed through a conductor in $32\,minutes$.

3. Calculate the resistance of a copper resistor of $30m$ long and $0.3mm$ diameter, assuming the resistivity of copper is $1.7 \times 10^{-8}\,\Omega\,m$.

4. What is the potential difference that is required to pass $5A$ through 30Ω?

5. A electric conductor tube has an inner tube diameter of $0.7cm$ and an outer diameter of $1cm$. Find the electric resistance if it has the length of $30cm$ and resistivity of $10^{-7}\Omega m$.

Resistance Variation with Temperature

1. Based on the table below, calculate the resistance at temperature T_f for each of the following cases:

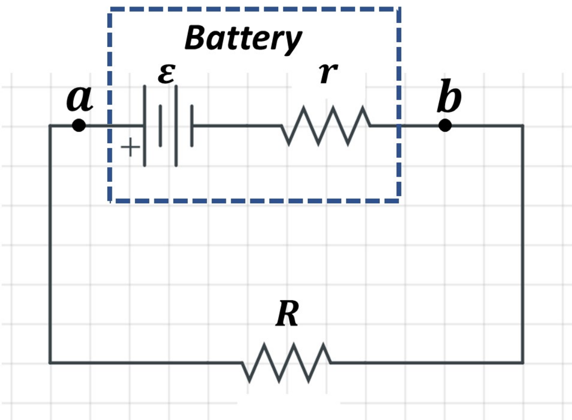
Question	R_i	T_f	T_i	α
a	200Ω	$47K$	$22K$	0.004041^oC^{-1}
b	$15k\Omega$	$5K$	$20K$	0.005671^oC^{-1}
c	100Ω	15^oC	$293.15K$	0.003715^oC^{-1}

a

2. Calculate temperature at which conductor has the resistance of 200Ω if the conductor has a thermal coefficient of resistance 0.0038^oC^{-1} and has a resistance of 150Ω at 50^oC.

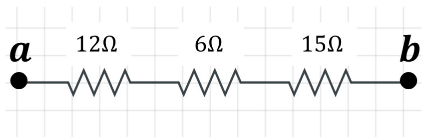
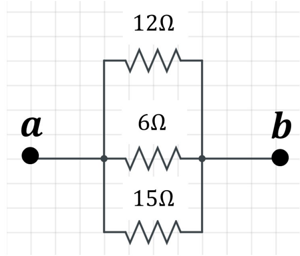
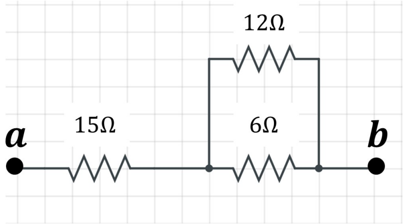
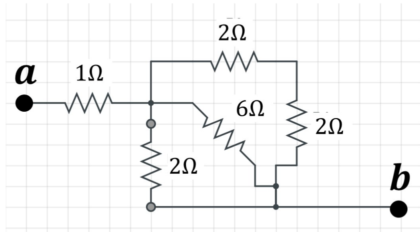
Electromotive Force, Series and Parallel Circuit

1. The figure below shows a simple circuit consisting of a battery and a resistor.



If the electromotive force of the battery is $9V$, the battery has an internal resistance of 0.5Ω and the resistor has a resistance of 6Ω, calculate the potential difference between points a and b.

2. Calculate the effective resistance between points a and b for each of the following diagram:

a) Case 1:	b) Case 2:
	
c) Case 3:	**d) Case 4:**
	

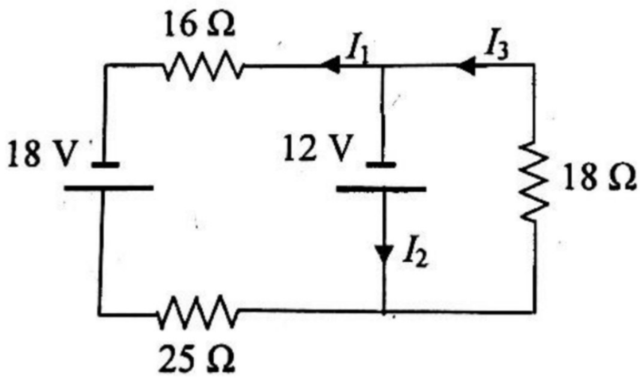
Tutorial Questions

Kirchhoff's Law

1. Calculate the values for x and y for the following pair of linear equations:

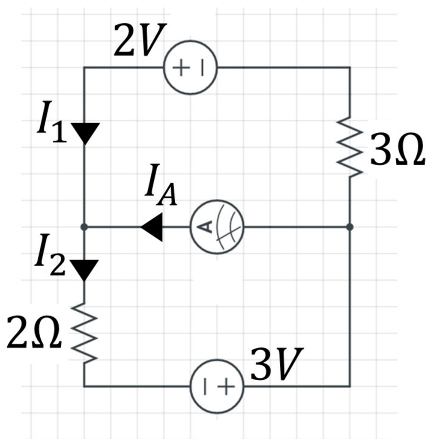
a)	$2x - 2y = 18$ $5x - 4y = 42$	b)	$4x = 14 + 2y$ $5y = 5x - 25$
c)	$x + 4y = 35$ $4x + 4y = 44$	d)	$x = 14 + y$ $4y = 4 - 3x$

2. **[PSPM 2014/2015]** The following diagram shows circuit consisting of 3 resistors and 2 emf.



Calculate I_1, I_2 and I_3, and the potential difference across the 18Ω resistor.

3. **[PSPM 2016/2017]** The following diagram shows circuit consisting of 2 batteries, 2 resistors and an ammeter.



If the ammeter has internal resistance of 5Ω, what is the reading shows by the ammeter?

4. **[PSPM 2017/2018]** The following diagram shows circuit consisting of 2 batteries and 3 resistors.

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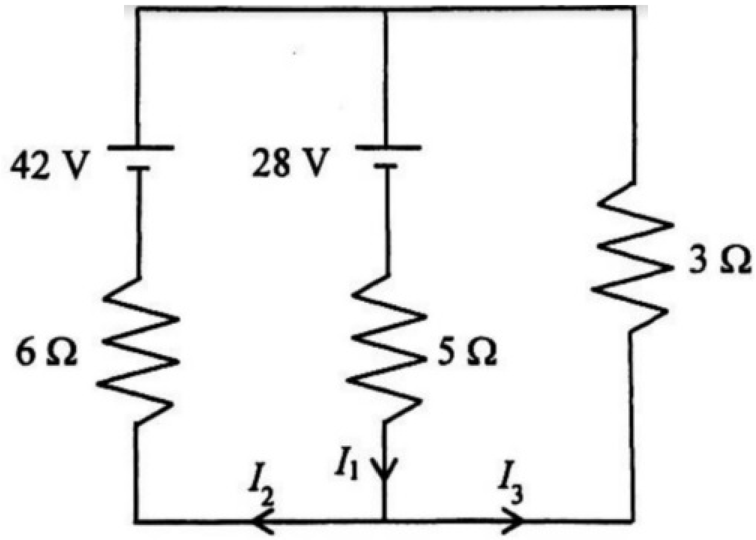
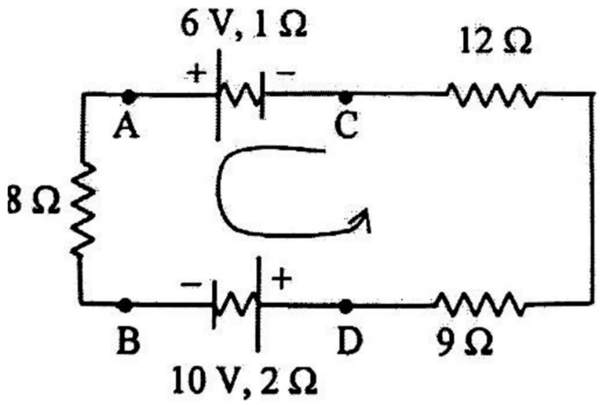


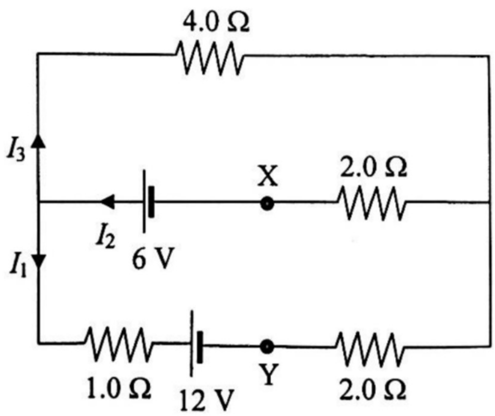
Calculate currents I_1, I_2 and I_3.

5. **[PSPM 2012/2013]** The following diagram shows circuit consisting of 2 batteries and 3 resistors.



By using the anticlockwise loop as shown, calculate the current that flows through the 8Ω resistor and the potential difference across point A and C, V_{AC}.

6. **[PSPM 2011/2012]** The following diagram shows circuit consisting of 2 batteries and 3 resistors.



(a) Calculate I_1, I_2 and I_3.

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(b) Calculate the potential difference between points X and Y.

(c) Calculate the total power dissipated in the circuit.

Electrical Energy and Power

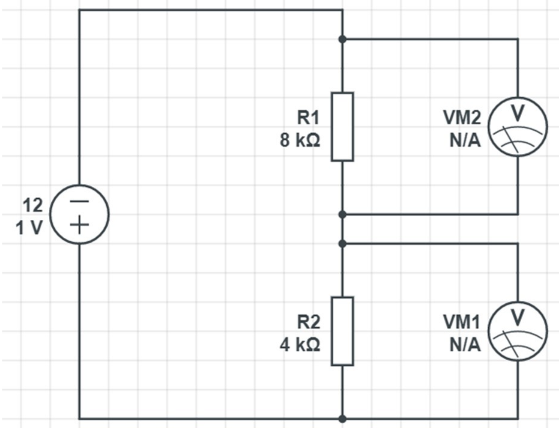
1. A 200Ω resistor has a current of $0.5A$ running through it, calculate the power lost through the resistor.

2. A bulb rated $120V/90W$ is operated from a 120V-source. Find the current running through it and the resistance of the bulb.

3. What is the resistance of a $1000W$ toaster running at $120V$? Calculate the heat energy dissipated if it was left running continuously for 2 minutes.

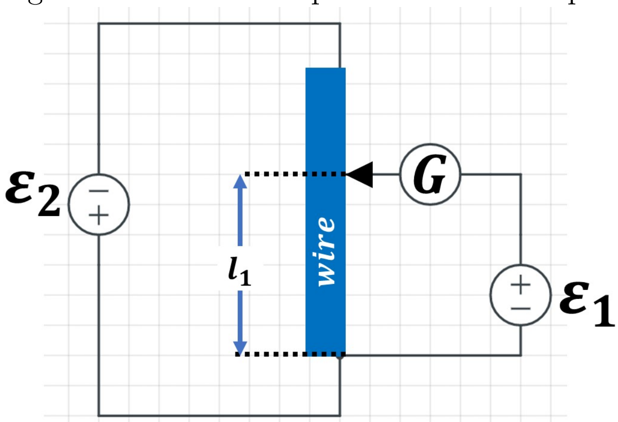
Potential Divider & Potentiometer

1. The following diagram shows circuit consisting of 1 battery, 2 voltmeters and 2 resistors.



   Calculate the voltmeter readings.

2. The diagram below shows a potentiometer setup.



   When $\varepsilon_2 = 1.5V$, the gavanometer gives a zero reading at $l_1 = 25cm$. What is the emf of ε_2 if the galvanometer gives a zero reading when $l_1 = 45cm$?

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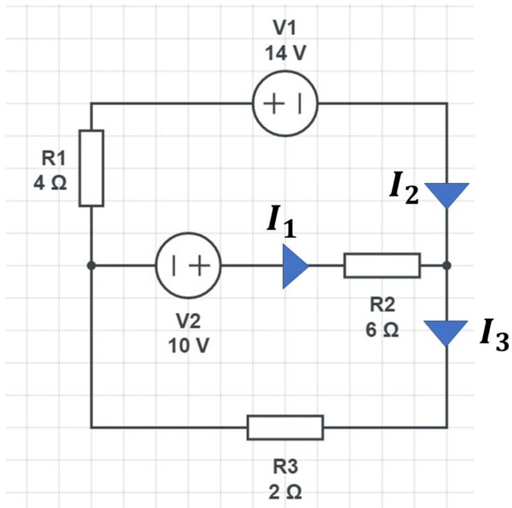
Extras

1. A wire $50m$ long and $2mm$ in diameter is connected to a source with a potential difference $9.11V$ and the current was found to be $36A$. Identify the metal out of which the wire is made out of.

2. Aluminium and copper wires of equal length are found to have the same resistance, what is the ratio of their radii?

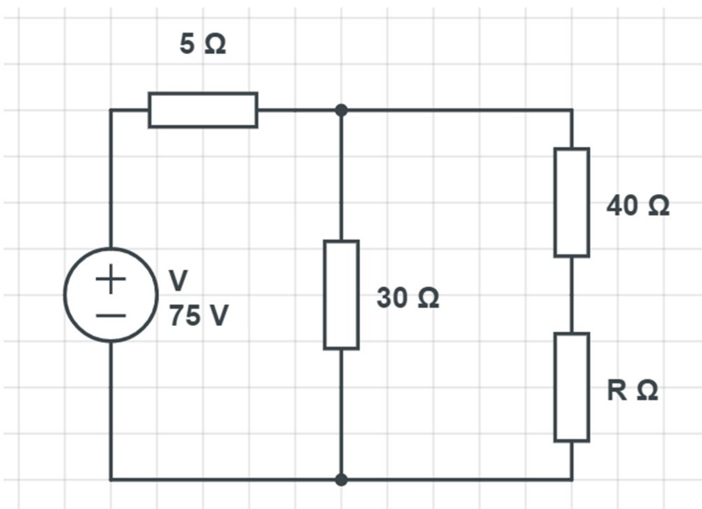
3. Calculate I_1, I_2 and I_3 in the figure below.



4. For $\tau = RC$, show that τ has units of time using Ohm's Law.

5. A lamp ($R = 150\Omega$), an electric heater ($R = 25\Omega$) and a fan ($R = 50\Omega$) are connected in parallel across a $120 - V$ line.
   Calculate the total current supplied to the circuit and the power expended by the heater.

6. The resistor R dissipates $20W$ of power, determine the value of R.



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Solutions:

Electric Conduction, Resistivity & Ohm's Law

1. $$I = \frac{Q}{t} \Rightarrow Q = It = (8A)(30s) = 240C$$

2. $$I = \frac{Q}{t} = \frac{Ne}{t} = \frac{(3 \times 10^{23})(1.6 \times 10^{-19})}{32 \times 60} = 25A$$

3. $$R = \rho \frac{l}{A}$$
$$R = (1.7 \times 10^{-8}\,\Omega\,m)\frac{30}{\pi\,(\frac{0.3\times10^{-3}}{2})^2}$$
$$R \approx 7.215\Omega$$

4. $$V = IR = (5A)(30\Omega) = 150V$$

5. $$A = \pi(r_{outer}^2 - r_{inner}^2) = \frac{\pi}{4}(d_{outer}^2 - d_{inner}^2)$$
$$R = \rho\frac{l}{A} = \rho\frac{l}{\frac{\pi}{4}(d_{outer}^2 - d_{inner}^2)}$$
$$R = \frac{(10^{-7})(30 \times 10^{-2})}{\frac{\pi}{4}((1 \times 10^{-2})^2 - (0.7 \times 10^{-2})^2)}$$
$$R = 0.75m\Omega$$

Resistance Variation with Temperature

1.

Question	R_f
a	220.205Ω
b	$13.724k\Omega$
c	98.1425Ω

2. $$R_f = R_i[1 + \alpha(T_f - T_i)]$$
$$T_f = \frac{\frac{R_f}{R_i} - 1}{\alpha} + T_i$$
$$T_f = \frac{\frac{200}{150} - 1}{0.0038} + (50)$$
$$T_f \approx 137.72^oC$$

Electromotive Force, Series and Parallel Circuit

1.
$$I = \frac{\varepsilon}{R+r} = \frac{9}{6+0.5} \approx 1.385V$$
$$V_{ab} = \varepsilon - rI = 9V - 0.5(1.385) \approx 8.3075V$$

2. (a) Case 1:
$$R_{eff} = 12 + 6 + 15 = 33\Omega$$

(b) Case 2:
$$R_{eff} = \left(\frac{1}{12} + \frac{1}{6} + \frac{1}{15}\right)^{-1}$$
$$R_{eff} = \frac{60}{19}\Omega$$

(c) Case 3:
$$R_{eff} = 15 + \left(\frac{1}{12} + \frac{1}{6}\right)^{-1}$$
$$R_{eff} = 19\Omega$$

(d) Case 4:
$$R_{eff} = 1 + \left(\frac{1}{2+2} + \frac{1}{6} + +\frac{1}{2}\right)^{-1}$$
$$R_{eff} = \frac{23}{11}\Omega$$

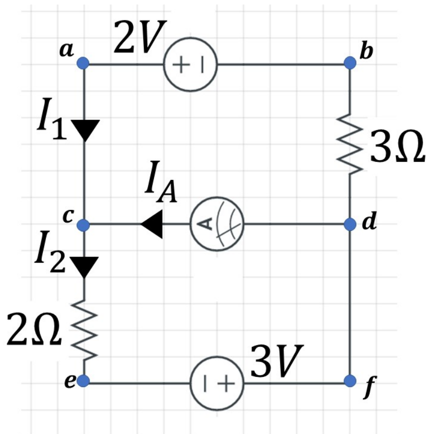
Kirchhoff's Law

1. Calculate the values for x and y for the following pair of linear equations:

a) $x = 6$, $y = -3$	b) $x = 2$, $y = -3$
c) $x = 3$, $y = 8$	d) $x = 4$, $y = -2$

2.

$$\sum I_{in} = \sum I_{out}$$
$$I_3 = I_1 + I_2$$
Take loop with emf 18V and 12V,
$$\sum \varepsilon = \sum V_{resistor}$$
$$\varepsilon_{18} - \varepsilon_{12} = I_1(R_{16} + R_{25})$$
$$18 - 12 = I_1(16 + 25)$$
$$I_1 = 0.15A$$
Take loop with emf 18Ω and 12V,
$$\varepsilon_{12} = I_3 R_8$$
$$I_3 = 0.67A$$
$$I_2 = I_3 - I_1 = 0.52A$$
$$V_{18\Omega} = I_3 R_{18} = 12V$$
$$I_i = \{0.15, 0.52, 0.67\}A$$



3.
$I_2 = I_A + I_1$ Loop abdca: $2 = -5I_A + 3I_1$ Loop efdce: $3 = 5I_A + 2I_2$ $I_A = 0.16A$

4.

Loop with resistors 5Ω and 6Ω :
$$42 - 28 = 5I_1 + 6I_2$$
$$5I_1 + 6I_2 = 14$$
Loop with resistors 5Ω and 3Ω :
$$5I_1 + 3I_3 = -28 I_i = \{-2,\ 4,\ -6\}A$$

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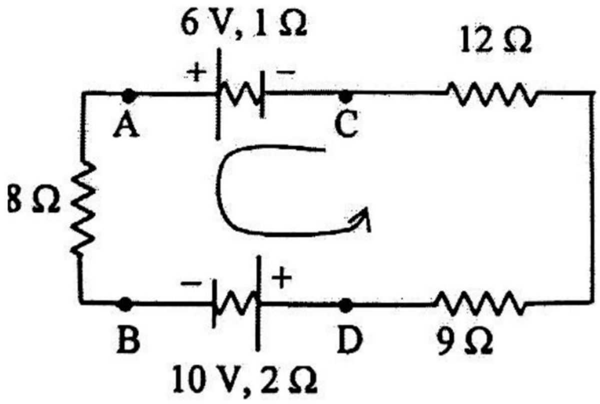
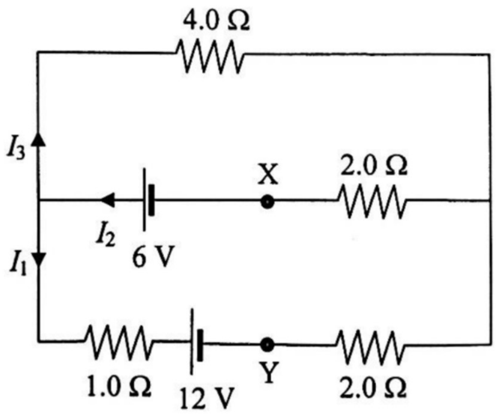
5. 

$$\text{Total emf,} \sum \varepsilon = 6V + 10V = 16V$$
$$\text{Total resistance,} \sum R = 2 + 12 + 9 + 1 + 8 = 18\Omega$$
$$\text{Current,} I = \frac{\sum \varepsilon}{\sum I} = \frac{16}{32} = 0.5A$$
$$V_{AC} = 6 - I(1) = 6 - 1(0.5) = 5.5V$$

6. 

(a)

$$I_2 = I_1 + I_3$$
$$Loop\,1:\ 6 - 12 = 3I_1 + 2I_2$$
$$Loop\,2:\ 6 = 4I_3 + 2I_2$$
$$I_i = \{-1.85, -0.23, 1.62\}A$$

(b) $\sum \varepsilon = \sum IR$ $V_{XY} + 6 - 12 = 1(-1.85)$ $V_{XY} = 4.15V$

(c) $P = \sum I^2 R = 20.9W$

Electrical Energy and Power

1. $P = IV = I^2R = (0.5)^2(200) = 50W$

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2. $I = \frac{P}{V} = \frac{90}{120} = 0.75A$
   $R = \frac{V}{I} = \frac{120}{0.75} = 160\Omega$

3. $P = IV = \frac{V^2}{R}$
   $R = \frac{V^2}{P} = \frac{(120)^2}{1000}$
   $W = Pt = (1000W)(120s) = 120kJ$

Potential Divider & Potentiometer

1. VM1: $V_1 = \frac{4000}{8000+4000}V_{source} = 4V$
   VM2: $V_1 = \frac{8000}{8000+4000}V_{source} = 8V$

2. $\frac{\varepsilon_1}{\varepsilon_2} = \frac{l_1}{l_2}$
   $\frac{1.5}{\varepsilon_2} = \frac{25}{45}$ $\varepsilon_2 = 2.7V$

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Extras

1.

$$
\begin{aligned}
R &= \frac{V}{I} = \frac{\rho l}{A} \\
\rho &= \frac{VA}{Il} = \frac{V(\frac{d}{2})^2}{Il} \\
\rho &= \frac{9.11 \times (\frac{2\times 10^{-3}}{2})^2}{36 \times 50m} \\
&\approx 1.59 \times 10^{-8}\Omega m \Rightarrow \text{Silver}
\end{aligned}
$$

2.

$$
\begin{aligned}
R_{Al} &= R_{Cu} \\
l_{Al} &= l_{Cu} \\
\rho_{Al} &= \frac{R_{Al}A_{Al}}{l_{Al}} \\
\rho_{Cu} &= \frac{R_{Cu}A_{Cu}}{l_{Cu}} \\
\frac{\rho_{Al}}{\rho_{Cu}} &= \frac{\frac{\cancel{R_{Al}}A_{Al}}{\cancel{l_{Al}}}}{\frac{\cancel{R_{Cu}}A_{Cu}}{\cancel{l_{Cu}}}} \\
\frac{\rho_{Al}}{\rho_{Cu}} &= \frac{A_{Al}}{A_{Cu}} = \frac{2.82}{1.7} \approx 1.66 \\
A_{Al} &= 1.66 \times A_{Cu} \\
\cancel{\pi} r_{Al}^2 &= 1.66 \cancel{\pi} r_{Cu}^2 \\
r_{Al}^2 &= 1.66\, r_{Cu}^2
\end{aligned}
$$

3.

Junction Rule:

$$I_3 = I_1 + I_2$$

Loop Rule:

$$
\begin{aligned}
10V &= 6I_1 + 2I_3 - - - (1) \\
14V &= -4I_2 - 2I_3 \\
14V &= -4(I_3 - I_1) - 2I_3 \\
14V &= 4I_1 - 6I_3 \\
I_i &= \{2,\ -3,\ -1\}A
\end{aligned}
$$

4.

$$\tau = RC = (\frac{V}{I})C = \frac{Q}{I} = t$$

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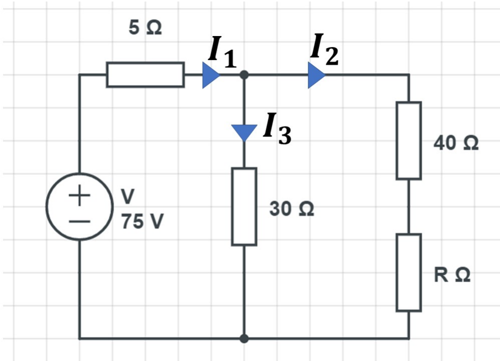
5.

$$V = IR$$
$$I = \frac{V}{R_{eff}} = \frac{12}{(\frac{1}{150} + \frac{1}{50} + \frac{1}{25})^{-1}} = 8A$$
$$P_{heater} = IV = I^2R = 8^2(25) = 1.6kW$$

6. 

Junction Rule:

$$I_1 = I_2 + I_3$$

Loop Rule - 1 :

$$75 = 5I_1 + 30I_3$$
$$75 = 5I_1 + 30I_1 - 30I_2$$
$$75 = 35I_1 - 30I_2$$

Loop Rule - 2 :

$$75 = 5I_1 + (40 + R)I_2$$
$$I_2 = \frac{450}{310 + 7R}$$
$$P = IV = I^2R$$
$$= (\frac{450\sqrt{R}}{310 + 7R})^2$$
$$\Rightarrow R = 20$$

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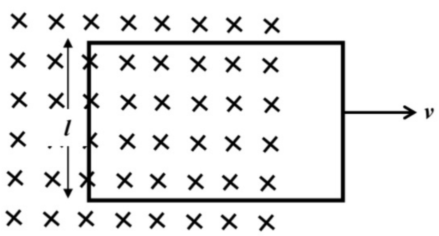
4 Chapter 5: Electromagnetic Induction

Magnetic Flux & Induced emf

1. State the definition and the SI unit of magnetic flux $\phi_{magnetic}$.
2. What is the difference between magnetic field strength and magnetic flux?
3. A quarter loop of area $15cm^2$ is placed in a region of magnetic field $0.16T$. Calculate the magnetic flux if the angle between the quarter loop area and the magnetic field is
   (a) 90^o
   (b) 70^o
   (c) 30^o
4. A loop of wire of area $40cm^2$ is placed in a magnetic field of strength $2cT$. Calculate the angle between the magnetic field and the wire loop if the magnetic flux is
   (a) $80\,\mu Wb$
   (b) $69\,\mu Wb$
   (c) $56\,\mu Wb$
5. A solenoid of cross-sectional area $60cm^2$ is placed in a magnetic field of strength $5cT$. The cross-sectional area of th solenoid is kept perpendicular to the magnetic field, and it was found that the magnetic flux to be $0.9Wb$. Calculate the number of turns found in the solenoid.
6. A circular coil of wire (of N turns, radius r) is placed in a magnetic field of strength B. The number of turns is then doubled, at what angle (between the magnetic field and cross-sectional area of solenoid) would the magnetic flux of the new solenoid be the same as the old solenoid (before it was doubled in number of turns)?
7. $2A$ current is flowed through a solenoid(of 10000 winding per metre, $80mm$ radius). Calculate the flux through the solenoid.
8. A magnetic field perpendicular to a circular coil (18 turns, radius $50mm$) changes from $2T$ to $20T$ in $3s$, Calculate the magnitude of the induced emf.
9. $3A$ current is flowed through a solenoid(of 5000 winding per metre, $60mm$ radius, $3cm$ length). Calculate the induced emf if the magnetic flux through it is increased by $1mWb$ in $240ms$.
10. The figure below shows a rectangular coil of 40 turns and length $l = 20cm$. It is pulled in a uniform magnetic field $B = 2T$



Calculate the magnitude and direction of the induced emf in the wire if the electrical resitance of the wire is $R = 5\Omega$ and the coil is pulled with a speed of $v = 20cm\, s^{-1}$.

11. An AC generator consisting a 30 turn coil with cross sectional area of $0.1m^2$ and resistance of 100Ω. The coild rotates in a magnetic field of strength $0.5T$ at a frequency of $30Hz$. Calculate the maximum induced current.

Self-Inductance

1. What is **self-inductance**? Explain the process.

2. Induced emf of $6V$ is developed across a coil when the current flowing through it changes at $30As^{-1}$. Determine the self-inductance of the coil.

3. If the current in a $230mH$ changes steadily from $20mA$ to $28mA$ in $140ms$. What is the induced emf?

4. Calculate the value of self-inductance for an air filled solenoid of length $5cm$ and cross-sectional area of $0.3cm^2$ containing 50 loops.

5. Suppose you wish to make a solenoid with a self inductance of $1.5mH$. Due to certain commercial constraints, it is imperative that the inductor must have a cross-sectional area of $2.2 \times 10^{-3}m^2$ and a length of $10cm$. How long of a wire would you need to make this solenoid?

6. A 500turns of solenoid is $8cm$ long. When the current in the solenoid is increased by $2.5A$ in $0.35s$, the magnitude of the induced emf is $0.012V$. Calculate the inductance of the solenoid and the cross sectional area of the solenoid.

Tutorial Questions

Inductor-stored Energy & Mutual Inductance

1. Two coils, X & Y are magnetically coupled. The emf induced in coil Y is $2.5V$ when the current flowing through coil X changes at the rate of $5As^{-1}$. Determine the mutual inductance of the coils and the emf induced in coil X if there is a current flowing through coil Y which changes at the rate of $1.5As^{-1}$.

2. The magnetic fild inside an air-filled solenoid $36cm$ long and $2cm$ in diameter is $0.85T$. Approximately how much energy is stored in this field?

3. A coil has an inductance 45 mH and resistance 0.3Ω. An emf of $12V$ is applied to the coil until equilibrium current is achieved. Calculate the energy stored in the coil.

4. A current of 5.0 A flows in a 400 turn solenoid that has a length of $30.0cm$ and cross-sectional area of $2.00 \times 10^{-4}m^2$. Calculate the energy stored in the solenoid.

5. An electric current of $1.5A$ flowing through a coil P produces a total magnetic flux of $0.540Wb$ in the coil. If a coil Q is brought near coil P, the total magnetic flux of 0.144 Wb is produced in coil Q.
   (a) Calculate the self—inductance of coil P, and determine the energy stored in coil P before coil Q is brought near it.
   (b) Calculate the mutual inductance of coil P with coil Q.
   (c) If the current in coil P is reduced uniformly from $1.5A$ to $0A$ in $0.3s$, determine the induced e.m.f of coil Q.

6. Two coaxial coils are wound around the same cylindrical core. The primary coil has 350 turns and the secondary coil has $200turns$. When the current in the primary coil $6.5A$, the average flux through each turn of the secondary coil is $0.018Wb$. Calculate the mutual inductance of the pair of coils.

7. A current of $3.0A$ flows in coil C and is produced a magnetic flux of 0.75 Wb in it. When a coil D is moved near to coil C coaxially, a flux of $0.25Wb$ is produced in coil D. If coil C has 1000 turns and coil D has 5000 turns.
   (a) Calculate self-inductance of coil C and the energy stored in C before D is moved near to it
   (b) Calculate the mutual inductance of the coils
   (c) If the current in C decreasing uniformly from $3.0A$ to zero in $0.25s$, calculate the induced emf in coil D.

Magnetic Flux & Induced emf Solution

1. $\phi_{magnetic} = \vec{B} \cdot \vec{A}$ where $\vec{A}$ is the vector perpendicular to the surface area and $\vec{B}$ is the magnetic field strength

2. Magnetic field strength is the amount of magnetizing force, the magnetic flux is a measurement of flux ("magnetic field lines") flowing through a surface.

3. A quarter loop of area $15cm^2$ is placed in a region of magnetic field $0.16T$. Calculate the magnetic flux if the angle between the quarter loop area and the magnetic field is
   (a) $90^o \Rightarrow \phi_B = (0.16)(0.15(10^{-2}))\,cos\,0^o = 0.00024\,Wb$

(b) $70^o \Rightarrow \phi_B = (0.16)(0.15(10^{-2}))\, cos\, 20^o = 0.00023\, Wb$

(c) $30^o \Rightarrow \phi_B = (0.16)(0.15(10^{-2}))\, cos\, 60^o = 0.00012\, Wb$

4. A loop of wire of area $40cm^2$ is placed in a magnetic field of strength $2cT$. Calculate the angle between the magnetic field and the wire loop if the magnetic flux is

(a) $80\, \mu Wb \Rightarrow \theta = 90^o - cos^{-1}(\frac{\phi}{BA}) = 90^o - cos^{-1}(\frac{80(10^{-6})}{(2(10^{-2}))(0.40(10^{-2}))}) = 90^o$

(b) $69\, \mu Wb \Rightarrow \theta = 90^o - cos^{-1}(\frac{\phi}{BA}) = 90^o - cos^{-1}(\frac{69(10^{-6})}{(2(10^{-2}))(0.40(10^{-2}))}) = 60^o$

(c) $56\, \mu Wb \Rightarrow \theta = 90^o - cos^{-1}(\frac{\phi}{BA}) = 90^o - cos^{-1}(\frac{56(10^{-6})}{(2(10^{-2}))(0.40(10^{-2}))}) = 44.427^o$

5. $N = \frac{\phi_B}{BAcos\theta} = \frac{0.9Wb}{60(10^{-4})(0.05)\, cos(90)} = 3000\,\text{turns}$

6.

$$\begin{aligned}
\Phi_{old} &= N_{old} B_{old} A_{old}\, cos\, \theta_{old} \\
\Phi_{new} &= N_{new} B_{new} A_{new}\, cos\, \theta_{new} \\
\Phi_{old} &= \Phi_{new};\; B_{old} = B_{old};\; A_{old} = A_{old} \\
N_{new} &= 2N_{old} \\
\theta_{new} &= cos^{-1}\left(\frac{1}{2}\, cos\, (\theta_{old})\right)
\end{aligned}$$

7.

$$\begin{aligned}
\phi &= BA \\
&= (\mu_o n I)(\pi r^2) \\
&= (4\pi \times 10^{-7})(10000)(2)\pi(80 \times 10^{-3})^2 \\
&= 51.2\pi^2\, \mu Wb
\end{aligned}$$

8.

$$\begin{aligned}
\varepsilon &= N\frac{d\phi}{dt} \\
&= NA\,\frac{dB}{dt} \\
&= (18)(\pi)(50 \times 10^{-3})^2\, \frac{20-2}{3} \\
&= 0.27\pi V
\end{aligned}$$

9.

$$\begin{aligned}
\varepsilon &= N\frac{d\phi}{dt} \\
&= (5000 \times 3(10^{-2}))\frac{10^{-3}}{240(10^{-3})} \\
&= 0.625V
\end{aligned}$$

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10.

$$\begin{aligned}
\varepsilon &= BLv \\
&= (2)(20\times10^{-2})(20\times10^{-2}) \\
&= 0.08V \\
I &= \frac{\varepsilon}{R} = \frac{0.08}{5} = 0.016 \\
F &= IlB\,sin\,90^o \\
&= (0.016)(0.02)(2) = 0.64\,mN
\end{aligned}$$

11. $I_{max} = \frac{\varepsilon_{max}}{R} = \frac{2\pi fNBA}{R} = \frac{(2\pi)(30)(30)(0.5)(0.1)}{100} = 0.9\pi\,A$

Self-Inductance

1. Self inductance is when the induced current creates another magnetic field which opposes the initial induced emf.
2. $L = -\frac{\varepsilon}{\left(\frac{dI}{dt}\right)}$ $L = -\frac{6}{(30)} = -5H$
3. $\varepsilon = -L\frac{dI}{dt} = -(230\times10^{-3})\frac{(28-20)(10^{-3})}{(140(10^{-3}))} = 0.01314286V$
4. $L = \frac{\mu_o N^2 A}{l} = \frac{(4\pi\times10^{-7})(50)^2(0.3\times10^{-4})}{(5\times10^{-2})} = 1.885\mu H$
5. $N^2 = \frac{Ll_{solenoid}}{\mu_o A} = \frac{(1.5(10^{-3}))(0.1)}{(4\pi\times10^{-7})(2.2\times10^{-3})}$
   $N \approx 233$ turns
   $l_{wire} = N(2\pi r) = N(2\pi\sqrt{\frac{A}{\pi}})$
   $l_{wire} = (233)(2\pi\sqrt{\frac{2.2\times10^{-3}}{\pi}}) = 38m$
6. $L = -\frac{\varepsilon}{\frac{dI}{dt}} = -\frac{0.012}{\frac{2.5}{0.35}} = 1.68mH$
   $L_{solenoid} = \frac{\mu_o N^2 A}{l}$
   $A = \frac{L_{solenoid}l}{\mu_o N^2}$
   $A = \frac{(1.68\times10^{-3})(0.08)}{(4\pi\times10^{-7})(500)^2} = 4.28\times10^{-4}m^2$

Inductor-stored Inductor & Mutual Inductance

1.

$$
\begin{aligned}
M &= -\frac{\varepsilon_Y}{\frac{dI_x}{dt}} \\
&= 0.5H \\
\varepsilon_X &= M\frac{dI_Y}{dt} \\
&= 0.75V
\end{aligned}
$$

2.

$$
\begin{aligned}
U &= \frac{1}{2}LI^2 \\
L &= \frac{\mu_o N^2 A}{l} \\
B &= \mu_o n I \frac{\mu_o N I}{l} \\
U &= \frac{1}{2}\frac{\mu_o N^2 A}{l}\frac{B^2}{2\mu_o}AL \\
&= 1.8 \times 10^{-10}J
\end{aligned}
$$

3.

$$M = \frac{N_2\phi_2}{I} = 0.55H$$

4. $U = 36J$
5. $U = 1.68mJ$
6. (a) $0.36H, 0.41J$
   (b) $0.096H$
   (c) $0.48V$
7. $M = \frac{N_2\phi_2}{I_1} = 0.55H$
8. A current of $3.0A$ flows in coil C and is produced a magnetic flux of 0.75 Wb in it. When a coil D is moved near to coil C coaxially, a flux of $0.25Wb$ is produced in coil D. If coil C has 1000 turns and coil D has 5000 turns.

   (a)

$$
\begin{aligned}
L_C &= \frac{N_C\Phi_C}{I_C} \\
&= \frac{1000 \times 0.75}{3} = 250H \\
U &= \frac{1}{2}L_C I_C^2 \\
&= \frac{1}{2}(250)(3)^2 = 1125J
\end{aligned}
$$

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(b)

$$
\begin{aligned}
M_D &= \frac{N_D \Phi_D}{I_C} \\
&= \frac{(5000)(0.25)}{(3)} \\
&= 417H
\end{aligned}
$$

(c)

$$
\begin{aligned}
\varepsilon_D &= -M\frac{dI_C}{dt} \\
&= -(417)\frac{-3}{0.25} \\
&= 5004V
\end{aligned}
$$