SP025
Physics Workbook

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Table of Content

One Page Notes

Chapter 1: Electrostatics

Coulomb's Law

$$F_{Coulomb} = \frac{kq_1q_2}{r_{12}^2}$$

$$k = \frac{1}{4\pi\epsilon} = 8.98 \times 10^9 \, kg \, m^3 \, s^{-4} \, A^{-2}$$

For more than 2 particles, the Coulomb Force on particle j becomes

$$F_{Coulomb} = kq_j \sum_i \frac{q_i}{r_{ij}^2}$$

The electric field at a point in space $E(r)$,

$$E(r) = \frac{F(r)}{q_{test}} = \frac{kq_{source}}{r^2}$$

Electric potential,

$$V = \frac{W_{\infty \to r}}{q_{test}} = \frac{kq_{source}}{r}$$

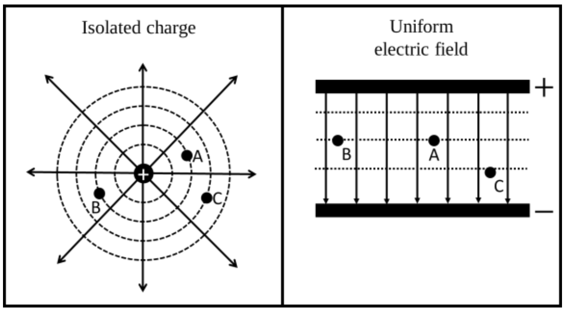
Electric potential energy,

$$U = q_{test}V$$

$$1eV = 1.6 \times 10^{-19} J$$

Equipotential lines and surfaces

= graphical representation on which a particle on the line or surfaces is at the same potential.



In both examples,

$$V_A = V_B \neq V_C$$

Charge in Uniform Electric Field,

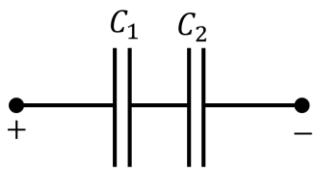
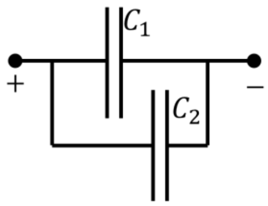
$$E = \frac{V}{d}$$

$$F = ma = qE$$

Chapter 2: Capacitors

Capacitance,

$$C = \frac{Q_{single\,plate}}{V} = \frac{\varepsilon A}{d}$$

Arrangement	Effective Capacitance
Series 	$\frac{1}{C_{eff}} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots + \frac{1}{C_n}$ $C_{eff} = \left(\sum_{i=1}^{n} \frac{1}{C_i}\right)^{-1}$
Parallel 	$C_{eff} = C_1 + C_2 + \cdots + C_n$ $C_{eff} = \sum_{i=1}^{n} C_i$

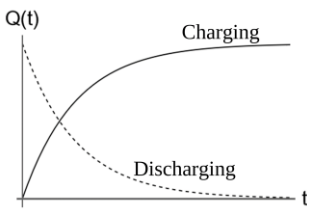
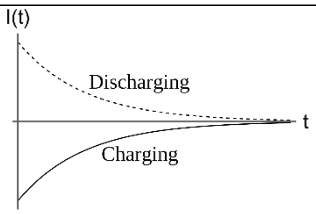
Energy Stored in Capacitor,

$$U = \frac{1}{2}\frac{Q^2}{C} = \frac{1}{2}CV^2 = \frac{1}{2}QV$$

Time Constant,

$$\tau = RC \text{ [seconds]}$$

Charging & Discharging

$Q - t$ graph	$I - t$ graph
 Discharging: $Q(t) = Q_o e^{-\frac{t}{RC}}$ Charging: $Q(t) = Q_o\left(1 - e^{-\frac{t}{RC}}\right)$	 Discharging: $I(t) = -\frac{dQ}{dt} = -\frac{Q_o}{RC}e^{-\frac{t}{RC}} = I_o e^{-\frac{t}{RC}}$ Charging: $I(t) = \frac{Q_o}{RC}e^{-\frac{t}{RC}} = -I_o e^{-\frac{t}{RC}}$

Dielectric Constant,

$$\varepsilon_r = \frac{C}{C_o} = \frac{\left(\frac{\varepsilon A}{d}\right)}{\left(\frac{\varepsilon_o A}{d}\right)} = \frac{\varepsilon}{\varepsilon_o}$$

Chapter 3: Current and DC Circuits

Electrical Current,

$$I = \frac{dQ}{dt}$$

Total Charge,

$$Q = ne$$

Ohm’s Law,

$$V \propto I \;\Rightarrow V = IR$$

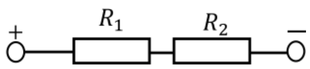
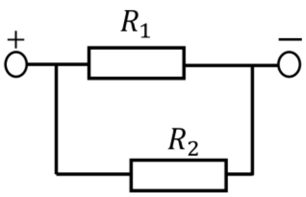
Resistance

Factor	Equations
Material	$R = \frac{\rho L}{A}$
Geometry	
Temperature	$\Delta R = \alpha \Delta T$

Electromotive force,

$$\varepsilon = IR + Ir = V + Ir$$

Resistors in parallel and series,

Arrangement	Effective Capacitance
Series 	$R_{eff} = R_1 + R_2$ For *n* number of resistors in **series**, $R_{eff} = R_1 + R_2 + \cdots + R_n = \sum_i^n R_i$
Parallel 	$\frac{1}{R_{eff}} = \frac{1}{R_1} + \frac{1}{R_2}$ For *n* number of resistors in **parallel**, $R_{eff} = \left(\frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}\right)^{-1} = \left(\sum_i^n \frac{1}{R_i}\right)^{-1}$

Kirchhoff’s Rules,

Rules	Statement
First Rule – Junction Rule (Conservation of Charge)	$\sum_i I_i = 0$
Second Rule – Loop Rule (Conservation of Energy)	$\sum_i V_i = 0$

Potential Divider,

$$V_o = \frac{R_1}{R_1 + R_2} V_s$$

Electrical Power,

$$P = IV = I^2 R = \frac{V^2}{R}$$

Chapter 5: Electromagnetic Induction

Magnetic Flux Linkage,

$$\Phi = N\phi = NBA\cos\theta$$

Induced emf (Faraday's & Lenz's Law),

$$\varepsilon = -\frac{d\phi}{dt}$$

Induced emf in straight conductor,

$$\varepsilon = -Bl\frac{dx}{dt} = Blv\sin\theta_{vB}$$

Induced emf in a coil,

$$\varepsilon = -NB\frac{dA}{dt} \textbf{ or } \varepsilon = -NA\frac{dB}{dt}$$

Induced emf in rotating coil,

$$\varepsilon = NBA\omega\sin(\omega t)$$

Self-Inductance,

$$L = -\frac{\varepsilon}{\left(\frac{dI}{dt}\right)} = \frac{N\phi}{I}$$

Self-Inductance in coil,

$$L = \frac{\mu_o N^2 A}{2r}$$

Self-Inductance in solenoid,

$$L = \frac{\mu_o N^2 A}{l}$$

Mutual Inductance,

$$M = -\frac{\varepsilon}{\left(\frac{dI}{dt}\right)} \text{ (General)}; \; M_{21} = \frac{\mu_o N_1 N_2 A_2}{l} \text{(two coaxial coils)}$$

Energy Stored in Inductor,

$$U = \frac{1}{2}LI^2$$

Chapter 6: AC Circuits

Rms Current and Voltage,

$$I_{rms} = \frac{I_o}{\sqrt{2}} \text{ and } V_{rms} = \frac{V_o}{\sqrt{2}}$$

Impedance,

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

Reactance,

Reactance	Equation
Capacitance reactance	$X_C = \frac{1}{2\pi f C}$
Inductive reactance	$X_L = 2\pi f L$

Phase Angle,

$$\theta_{IV} = tan^{-1}\left(\frac{X_L - X_C}{R}\right)$$

Resonance occurs when $X_L = X_C \Rightarrow \omega = \frac{1}{\sqrt{LC}} = 2\pi f$.

Resonant frequency,

$$f_o = \frac{1}{2\pi\sqrt{LC}}$$

Powers,

$$P = I(t) \times V(t)$$
$$P_{ave} = I_{rms}V_{rms}\cos(\theta_{IV})$$

Power Factor,

$$\cos\theta_{IV} = \frac{P_{real}}{P_{apparent}} = \frac{P_{ave}}{I_{rms}V_{rms}}$$

Chapter 7: Optics

Reflection upon curved mirror,

Radius and focal length, $R = 2f$

Magnification, $m = \frac{h_i}{h_o}$

Mirror Equation, $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

Refraction upon curved surface,

$$\frac{n_1}{u} + \frac{n_2}{v} = \frac{n_2 - n_1}{R}$$

Thin Lenses,

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v} = \left(\frac{n_{material}}{n_{medium}} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Double Slits,

For bright fringes,

$$\Delta\phi = \frac{y_m d}{D} = m\lambda$$

Single Slits,

For bright fringes,

$$y_n = \frac{(n + 0.5)\lambda D}{d}$$

Diffraction grating,

For bright fringes,

$$d \sin \theta_n = n$$

Thin Films,

Condition	Maxima	Minima
$n_1 < n_2; n_2 > n_3$	$2nt = (m - 0.5)\lambda$	$2nt = m\lambda$
$n_1 < n_2 < n_3$	$2nt = m\lambda$	$2nt = (m + 0.5)\lambda$
Minimum Thickness	$t = \frac{\lambda}{4n}$	$t = \frac{\lambda}{2n}$

Chapter 8: de Broglie Wavelength

$$\lambda_{matter} = \frac{h}{p} = \frac{h}{mv} = \frac{h}{\sqrt{2qVm}}$$

Chapter 9 Nuclear & Particle Physics

Mass Defect,

$$\Delta m = \left(Zm_{proton} + Nm_{neutron}\right) - m_{nucleus}$$

Binding Energy,

$$E_{binding} = \Delta mc^2$$

Decay law,

$$\frac{dN}{dt} = -\lambda N \;\Rightarrow N(t) = N_o e^{-\lambda t}$$

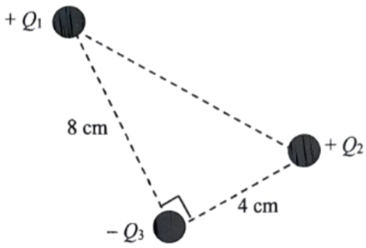
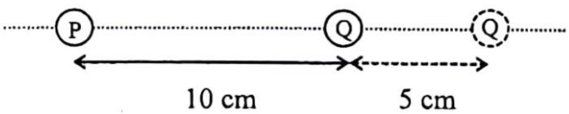
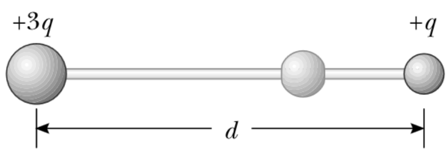
Activity,

$$A = A_o e^{-\lambda t}$$

Half-life,

$$T_{\frac{1}{2}} = \frac{ln\,2}{\lambda}$$

Exercise Sheet 1: Coulomb's Law & Electric Field

Easy	
1	Two point charges of $+2\mu C$ and $-4\mu C$ are separated by 2cm. Determine the electric force between them.
2	A point charge has a charge of $-2\mu C$. Determine the electric field 2cm from the point charge.
3	A point charge of $2\mu C$ is placed in a region of electric field of $200NC^{-1}$. Calculate the magnitude of force acting on the point charge?
Past Year	
4	**PSPM 21/22 – Q1(a)** Two opposite charges of the same magnitude of $2 \times 10^{-7}C$ are separated by 15cm. Calculate the a. Electric field strength at the midpoint between both charges. b. Magnitude of the force exerted on an electron on that point.
5	**PSPM 20/21 – Q1(a)** The figure shows three fixed point charges, $Q_1 = +12nc$, $Q_2 = +3nC$ and $Q_3 = -4nC$.  Sketch the electric force diagram on the charge Q_3. Addition: Calculate the electric force on Q_3.
6	**PSPM 19/20 – Q1(a)**  The electric field at a point 10cm away from a charge P as shown in the diagram is $2.7(10^6)NC^{-1}$. a. Determine the charge of P. b. Sketch the electric force vectors on charge P and Q. c. If charge Q is moved horizontally to the right to a new position, and the electric force on it is $-4.05N$, how far apart is charge Q from charge P?
Book	
7	Two small nonconducting spheres have a total charge of $90\mu C$. When placed 28.0 cm apart, the force each exerts on the other is 12.0 N and is repulsive. What is the charge on each? What if the force were attractive?
8	Two spherical objects are separated by a distance that is $1.80 \times 10^3 m$. The objects are initially electrically neutral and are very small compared to the distance between them. Each object acquires the same negative charge due to the addition of electrons. As a result, each object experiences an electrostatic force that has a magnitude of $4.55 \times 10^{-21}N$. How many electrons did it take to produce the charge on one of the objects?
9	Two small beads having positive charges 3q and q are fixed at the opposite ends of a horizontal, insulating rod, extending from the origin to the point x = d. As shown in the figure, a third small charged bead is free to slide on the rod. At what position is the third bead in equilibrium? 

Exercise Sheet 2: Electric Potential & Potential Energy

Easy

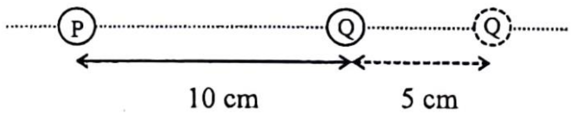
1 The energy needed to bring a $2\mu C$ to point A is $20 \times 10^{6} J$. Determine the electric potential at that point.

2 Referring to question 1, if point A is 30cm from a point charge Q. determine the charge of Q.

3 A system of charges consists of two point charges of $+2\mu C$ and $-4\mu C$ are separated by 2cm. Determine the electric potential energy of the system.

Past Year

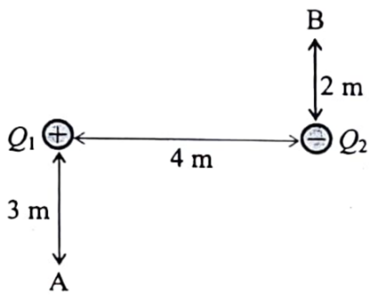
4 **PSPM 19/20 – Q1(a)**



The electric field at a point 10cm away from a charge P as shown in the diagram is $2.7(10^{6})NC^{-1}$. A charge Q is placed 10cm away from charge P. When charge Q is moved horizontally to the right to a position 5cm from its initial position, there is a 0.54J change in its electric potential energy of the system. What is the charge of Q?

5 **PSPM 18/19 – Q1(a)**

The figure shows two charges, $Q_1 = +8\mu C$ and $Q_2 = -6\mu C$ placed 4m apart.

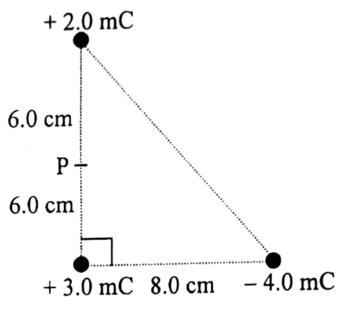


Calculate

a. the electric potential at points A and B.
b. the electric potential difference between points A and B.

6 **PSPM 16/17 – Q1(b)**

The figure shows three-point charges placed at each vertices of a right angle triangle.

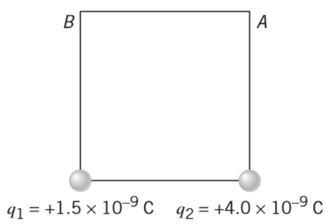


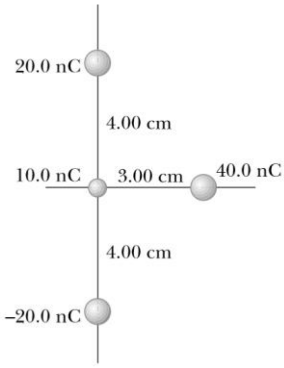
Calculate the

a. electric potential at point P
b. electric potential energy of the system.

Book

7 The drawing shows a square, each side of which has a length of L = 0.25 m. On two corners of the square are fixed different positive charges, $q_1 (= +1.5nC)$ and $q_2 (= +4nC)$. Find the electric potential energy of a third charge $q_3 = -6nC$ placed at corner A and then at corner B.

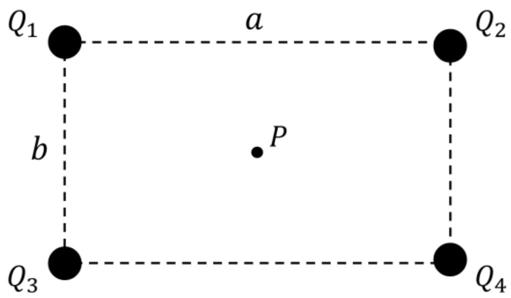


8	How much work must be done to bring three electrons from a great distance apart to $10^{-10}m$ from one another (at the corners of an equilateral triangle)?
9	Two particles, with charges of 20nC and –20nC, are placed at the points with coordinates (0, 4cm) and (0, –4cm), as shown in the figure. A particle with charge 10nC is located at the origin. i. Find the electric potential energy of the configuration of the three fixed charges. ii. A fourth particle, with a mass of $2(10^{-13}kg)$ and a charge of 40nC, is released from rest at the point (3cm, 0). Find its speed after it has moved freely to a very large distance away. 

Exercise Sheet 3: Sample Problem – 4 Charges

Problem

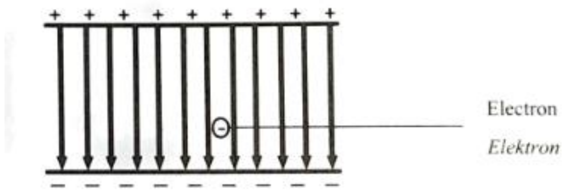
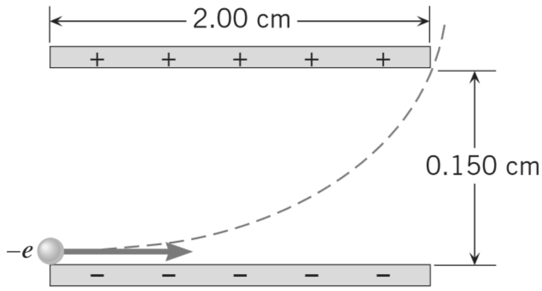
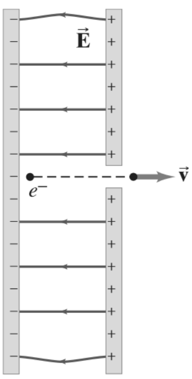
4 charges, $Q_1 = +2\mu C$, $Q_2 = +3\mu C$, $Q_3 = -3\mu C$, $Q_1 = -5\mu C$, are placed in an arrangement as shown in the diagram below.



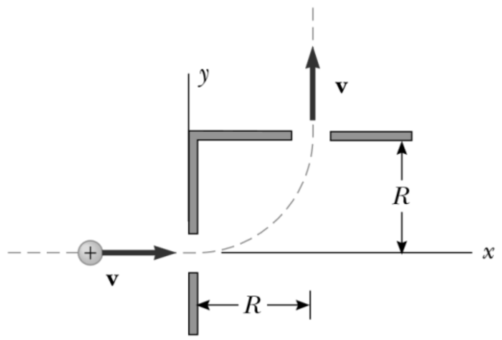
If length of side a is the same as length of side b at 2cm, calculate

a. the net force exerted on a charge of $+0.25\mu C$ placed at P, the centre of the rectangle.
b. the electric field experience by a test charge placed at P, the centre of the rectangle.
c. the total electrical potential energy of the system.
d. the change in potential energy moving Q_4 from its original position to position P, the centre of the rectangle.

Exercise Sheet 4: Charge In Uniform Electric Field

Easy	
1	Two charged parallel plates are separated by a distance 2.5cm. The potential difference between the plates is 2kV. Find the electric field strength between the plates.
2	An electron is placed between two charged parallel plates of potential difference 40V separated by 5cm. Determine the force experienced by the electron.
3	A charged body of mass 20g and 2mC is placed between two charged parallel plate of potential 20V and 40V. Determine the acceleration of the charged body.
Past Year	
4	**PSPM 21/22 – Q1 (b)** The figure shows a uniform electric field $395 Vm^{-1}$ exists in a region between two oppositely charged plates. An electron is released from rest at the surface of the negatively charged plate and strikes the surface of opposite place, 2cm away.  Calculate the a. acceleration of the electron b. potential difference between the plates work done by the electric field.
5	**PSPM 20/21 – Q1(b)** A small ball with mass 25g has a total charge of q=+20μC is placed between two parallel charged plates. i. In static equilibrium, determine the magnitude of the electric field in the plates. ii. Calculate the acceleration of the ball if moves horizontally parallel with electric field.
6	**PSPM 19/20 – Q1(b)** Two oppositely charged parallel plates are held 2mm apart. A $4 \times 10^{-5} J$ of work is needed to move a 2μC point charge from one plate to the other. Calculate the electric field between the plates.
Book	
7	The drawing shows an electron entering the lower left side of a parallel plate capacitor and exiting at the upper right side. The initial speed of the electron is $7 \times 10^{6} ms^{-1}$. The capacitor is 2cm long, and its plates are separated by 0.150 cm. Assume that the electric field between the plates is uniform everywhere and find its magnitude. 
8	An electron is accelerated in the uniform field ($E = 14.5\ kNC^{-1}$) between two thin parallel charged plates. The separation of the plates is 1.60 cm. The electron is accelerated from rest near the negative plate and passes through a tiny hole in the positive plate, as shown in the figure. With what speed does it leave the hole? Show that the gravitational force can be ignored. 

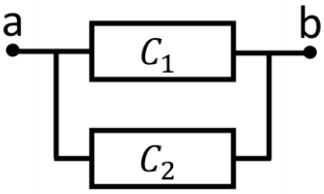
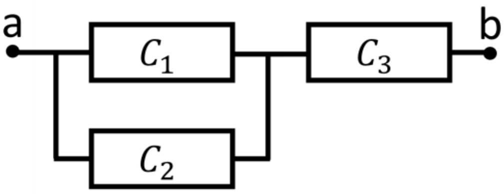
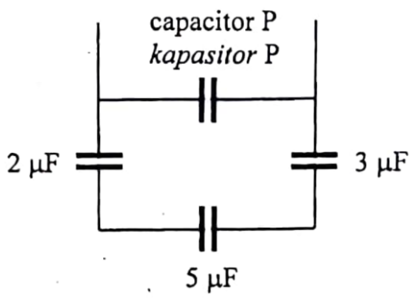
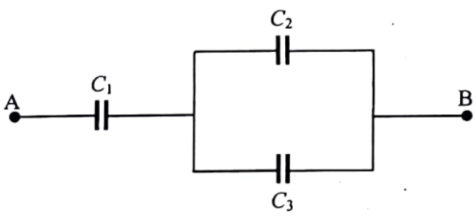
9 A researcher studying the properties of ions in the upper atmosphere wishes to construct an apparatus with the following characteristics: Using an electric field, a beam of ions, each having charge q, mass m, and initial velocity $v\hat{\imath}$, is turned through an angle of 90° as each ion undergoes displacement $R\hat{\imath} + R\hat{\jmath}$. The ions enter a chamber as shown in the figure, and leave through the exit port with the same speed they had when they entered the chamber. The electric field acting on the ions is to have constant magnitude.

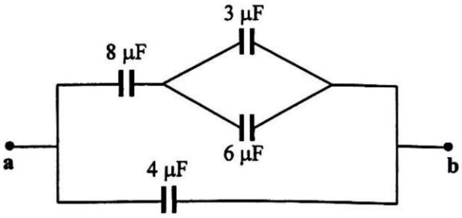
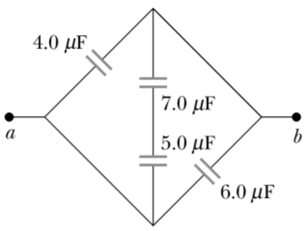


a. Suppose the electric field is produced by two concentric cylindrical electrodes not shown in the diagram, and hence is radial. What magnitude should the field have?

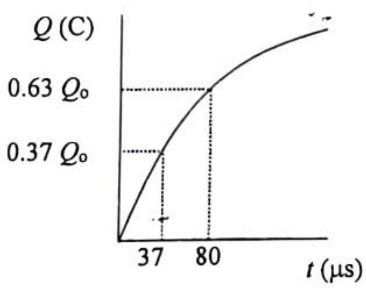
b. If the field is produced by two flat plates and is uniform in direction, what value should the field have in this case?

Exercise Sheet 5: Capacitors In Series & Parallel

Easy	
1	Determine the effective capacitance between a and b for the following diagram if $C_1 = 2\mu F$; $C_2 = 4\mu F$; and $C_3 = 3\mu F$. i.  ii.  iii. 
2	Referring to question 1, determine the energy stored if the potential difference between a and b is 12V.
3	A capacitor consists of two parallel plates, each of area $20cm^2$ and separated by 0.25cm of air. Determine the capacitance of the capacitor.
Past Year	
4	**PSPM 19/20 – Q2**  Capacitor P along with other capacitors are arranged as shown in the figure. If capacitor P has a capacitance of $4\mu F$, determine the effective capacitance.
5	**PSPM 18/19 – Q2** The figure shows three capacitors C_1, C_2, and C_3, each $12\mu F$ connected between points A and B. a. Calculate the effective capacitance. b. If the potential difference across AB is 9V, calculate the stored energy. 
6	**PSPM 17/18 – Q1(d)**

	 The figure shows a circuit consists of four capacitors. Calculate the equivalent capacitance between terminals a and b.
Book	
7	A. Two capacitors, $C_1 = 5\mu F$ and $C_2 = 12\mu F$, are connected in parallel, and the resulting combination is connected to a 9.00-V battery. a. What is the equivalent capacitance of the combination? b. What are the potential difference across each capacitor c. What are the charge stored on each capacitor? B. The two capacitors are now connected in series and to a 9.00-V battery. Find a. the equivalent capacitance of the combination, b. the potential difference across each capacitor, c. the charge on each capacitor.
8	Consider three capacitors C_1, C_2, C_3, and a battery. If C_1 is connected to the battery, the charge on C_1 is 30.8μC. Now C_1 is disconnected, discharged, and connected in series with C_2. When the series combination of C_2 and C_1 is connected across the battery, the charge on C_1 is 23.1μC. The circuit is disconnected and the capacitors discharged. Capacitor C_3, capacitor C_1, and the battery are connected in series, resulting in a charge on C_1 of 25.2μC. If, after being disconnected and discharged, C_1, C_2 and C_3 are connected in series with one another and with the battery, what is the charge on C_1?
9	Find the equivalent capacitance between points a and b in the combination of capacitors shown in the figure. 
10	Two capacitors, $C_1 = 25.0\mu F$ and $C_2 = 5.00\mu F$, are connected in parallel and charged with a 100-V power supply. a. Draw a circuit diagram and calculate the total energy stored in the two capacitors. b. What potential difference would be required across the same two capacitors connected in series in order that the combination stores the same amount of energy as in (a)? Draw a circuit diagram of this circuit.

Exercise Sheet 6: Charging & Discharging of Capacitors

Easy	
1	A capacitor consists of two parallel plates, each of area $20cm^2$ and separated by 0.25cm of air. If the capacitor is connected to a power supply of 12V and a resistor of 2Ω. Determine the time constant.
2	A 6pF capacitor fully charged is connected to a 20Ω resistor. Determine the time it takes to discharge the capacitor to half of its capacity.
3	An uncharged 50μF capacitor is connected to a 4MΩ resistor and a 12V battery. a. Determine the time is takes to charge from 0% to 80% maximum capacity. b. Compare this to the time it takes to charge from 80% to 99% maximum capacity.
Past Year	
4	**PSPM 21/22 – Q2(b)** A $12\mu F$ capacitor which is charged to 6V, is connected in series to $8M\Omega$ resistor and a switch. Determine the charge on the capacitor 4 minutes after the switch is closed.
5	**PSPM 20/21 – Q2** An uncharged capacitor of $58\mu F$ is connected in series with a resistor of $100k\Omega$. Then the capacitor starts charging through the resistor. Calculate the time required for the capacitor to reach 30% of its maximum charge.
6	**PSPM 19/20 – Q2(a)** The graph in the figure shown shows how the charge Q on a capacitor P change with time, t when it is charged through a 20Ω resistor. Determine the capacitance of capacitor P. 
Book	
7	An uncharged capacitor with capacitance C is connected in series with a resistor R. A power supply of V_o is supplied across the circuit. Calculate the time taken for the potential difference across the capacitor increase to 72% the value of V_o.
8	A 2nF with an initial charge of 5.1μC is discharged through 1.3kΩ resistor. a. Calculate the current in the resistor $9\mu s$ after the resistor is connected across the terminals of the capacitor. b. Find the charge remains on the capacitor after $8\mu s$. c. Determine the maximum current in the resistor.
9	A 10μF capacitor is charged to $650\mu C$ through a 20kΩ resistor. a. Calculate the time constant for this charging process. b. Calculate the initial current through the resistor.

Exercise Sheet 7: Dielectrics

Easy	
1	A material has a dielectric constant of 2. Determine its dielectric permittivity of the material.
2	The material in question 1 is placed in between the plates of a parallel plate capacitor which has an initial capacitance of $4\mu F$. Determine the capacitance of the capacitor after the material is inserted.
3	A parallel plates capacitor has surface area of $305cm^2$ and a plate separation of 0.4cm. If the space between the plate is air-filled, determine the capacitance of the capacitor.
Past Year	
4	**PSPM 21/22 – Q2(a)** A parallel plate capacitor consists of plates of area $0.35m^2$ and separated by 10mm. If the region between plates is filled with dielectric material with dielectric $\varepsilon_r = 5.5$; calculate its capacitance.
5	***Not from past year** A dielectric material is inserted in between the plates of $8.9\mu F$ parallel plate capacitor. Calculate the capacitance of the capacitor if the dielectric constant of the material is 6.5.
6	***Not from past year** A parallel plate capacitor in a vacuum has a plate separation of 1.3cm with a plate area of $30cm^2$. A potential difference of 250V charges the plate and then it disconnected from the source. The capacitor is then dipped in distilled water with a dielectric constant of 80. a. Determine the charge on the plates before and after the dipping. b. Calculate the capacitance and potential difference after the dipping. c. Calculate the change in energy of the capacitor.
Book	
7	Two capacitors are identical, except that one is empty and the other is filled with a dielectric (ε_r =4.50). The empty capacitor is connected to a 12V battery. What must be the potential difference across the plates of the capacitor filled with a dielectric so that it stores the same amount of electrical energy as the empty capacitor?
8	An empty parallel plate capacitor is connected between the terminals of a 9V battery and charged up. The capacitor is then disconnected from the battery, and the spacing between the capacitor plates is doubled. As a result of this change, what is the new voltage between the plates of the capacitor?
9	A parallel-plate capacitor in air has a plate separation of 1.5cm and a plate area of $25cm^2$. The plates are charged to a potential difference of 250V and disconnected from the source. The capacitor is then immersed in distilled water. Determine a. the charge on the plates before and after immersion, b. the capacitance and potential difference after immersion, c. the change in energy of the capacitor. Assume the liquid is an insulator.

Exercise Sheet 8: Electric Current, Resistivity, Ohm's Law & Temperature

Easy

1 Current running through a wire is found to be 1.5A. Determine the number of electron going through a section of this wire in 2s.

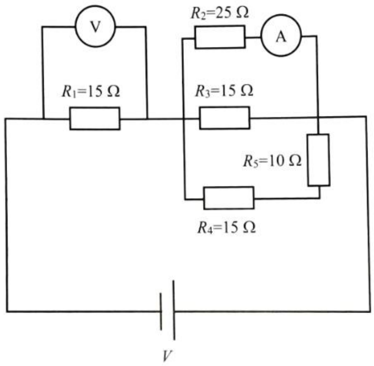
2 A material has a cross-sectional area of $20cm^2$ and length of 4cm. If the material has a measured resistance of 20Ω, determine its resistivity.

3 A $24k\Omega$ resistor is connected to a power supply of 240V. Determine the current going through the wire. The resistor then heated up by 30K, determine the new value for current after the resistor has heated up.

Past Year

4 **PSPM 21/22 – Q3**

a. A conducting wire has a 1.0mm diameter, a 2.0m length and a 50 mΩ resistance. Calculate its resistivity.
b. The figure shows a circuit consisting five resistors, a voltmeter and an ammeter connected to a battery.



The reading of the ammeter is 1.25A. Determine the voltmeter reading.

5 **PSPM 18/19 – Q3(a)**

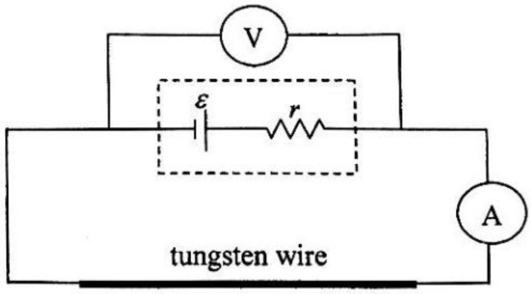
Calculate the number of electrons that flow in a wire if it carries a current of 2A for 5 s.

6 **PSPM 19/20 – Q3(a)(iv)**

Determine the change in resistance of a 2Ω resistor when there is a 30^oC rise in its temperature. The temperature coefficient of the resistivity of the resistor is $6.8 \times 10^{-3} {}^oC^{-1}$.

7 **PSPM 15/16 – Q2(a)**

The figure shows a tungsten wire connected to a battery with internal resistance $r = 0.6\Omega$. At room temperature of 23^oC, the readings of voltmeter and ammeter are 8.74V and 437mA respectively. After the tungsten wire is heated to 190^oC, the voltmeter reading is 8.85V and the ammeter reading is 253 mA. Calculate the temperature coefficient of resistivity of tungsten wire.

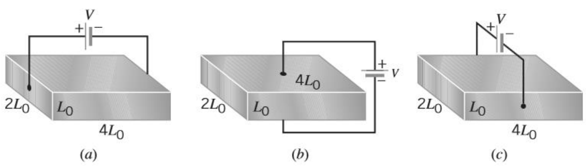


Book

8 Suppose that the resistance between the walls of a biological cell is $5\times 10^9\Omega$.

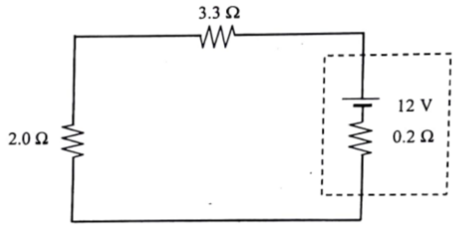
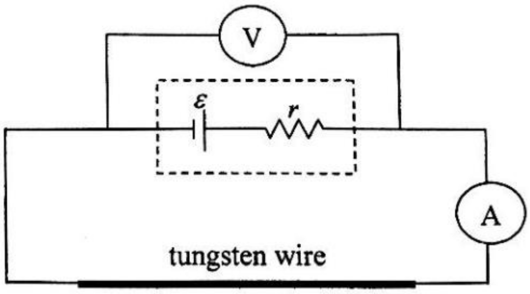
a. What is the current when the potential difference between the walls is 75 mV?
b. If the current is composed of Na^+ ions (q=+e), how many such ions flow in 0.50s?

9 The resistance and the magnitude of the current depend on the path that the current takes. The drawing shows three situations in which the current takes different paths through a piece of material.



	Each of the rectangular pieces is made from a material whose resistivity is $1.5 \times 10^{-2} \Omega m$, and the unit of length in the drawing is $L_o = 5cm$. Each piece of material is connected to a 3V battery. Find the resistance and the current in each case.
10	While taking photographs in Death Valley on a day when the temperature is 58.0°C, Bill Hiker finds that a certain voltage applied to a copper wire produces a current of 1A. Bill then travels to Antarctica and applies the same voltage to the same wire. What current does he register there if the temperature is -88.0°C? Assume that no change occurs in the wire's shape and size.

Exercise Sheet 9: Electromotive Force

Easy	
1	(a) What is the current in a 5.6Ω resistor connected to a battery that has a 0.2Ω internal resistance if the terminal voltage of the battery is 10.0 V? (b) What is the emf of the battery?
Past Year	
2	**PSPM 18/19 – 3(c)** The figure shows a circuit with a battery having an emf of 12V and an internal resistance of 0.2Ω connected in series to two resistors, 3.3Ω and 2.0Ω. a. Calculate the current in the circuit. b. Calculate the terminal voltage across the battery. 
3	**PSPM 15/16 – Q2(a)** The figure shows a tungsten wire connected to a battery with internal resistance r. At room temperature of 23^oC, the readings of voltmeter and ammeter are 8.74V and 437mA respectively. After the tungsten wire is heated to 190^oC, the voltmeter reading is 8.85V and the ammeter reading is 253 mA. Calculate emf and internal resistance of the battery. 
4	**PSPM 14/15 – Q2(b)** A battery has an emf of 9 V. The terminal voltage is 8V when the battery is connected across a resistor of 5 Ω. Calculate the current through the resistor and the internal resistance of the battery.
Book	
5	An automobile battery has an emf of 12.6V and an internal resistance of 0.08Ω. The headlights together present equivalent resistance 5Ω (assumed constant). What is the potential difference across the headlight bulbs (a) when they are the only load on the battery and when the starter motor is operated, taking an additional 35.0 A from the battery?
6	Two 1.50-V batteries — with their positive terminals in the same direction are inserted in series into the barrel of a flashlight. One battery has an internal resistance of 0.255Ω the other an internal resistance of 0.153 Ω. When the switch is closed, a current of 600 mA occurs in the lamp. a. What is the lamp’s resistance? b. What fraction of the chemical energy transformed appears as internal energy in the batteries?

Exercise Sheet 10: Resistors in Parallel & Series

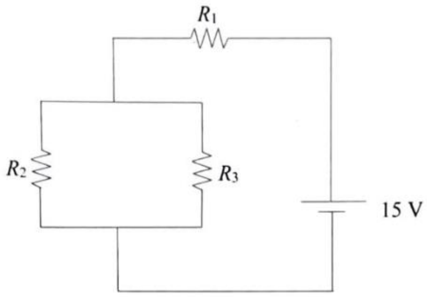
Easy

1 Two resistors of 3Ω are connected in series to a power supply of 4V.
Determine the effective resistance, current of the circuit and the voltage across ends of each resistor.

2 Two resistors of 3Ω are connected in parallel to a power supply of 4V.
Determine the effective resistance and current through each resistor.

Past Year

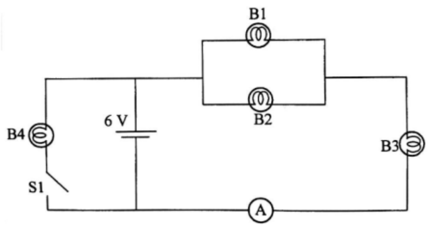
3 **PSPM 20/21 – 3(c)**
The figure shows $R_1 = 10\Omega$; $R_2 = 12\Omega$ and $R_3 = 5\Omega$ are connected to a 15V power supply.



a. Calculate the effective resistance
b. Potential difference across R_3.

4 **PSPM 16/17 – Q2(b)(i)**
You are given several $1k\Omega$ resistors. How do you connect the resistors to a circuit that requires a 500 Q resistance? Show your suggestion.

5 **PSPM 15/16 – Q2(b)(i)**



The figure shows four identical bulbs connected to a 6 V battery and a switch. When the switch is off, the ammeter reading is 0.5 A.

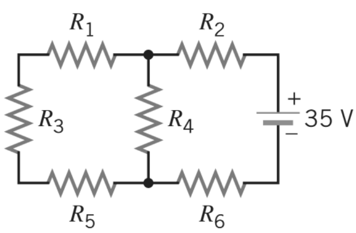
a. Calculate the resistance of a bulb.
b. What happen to the reading of the ammeter when the switch is on? Explain your answer.

Book

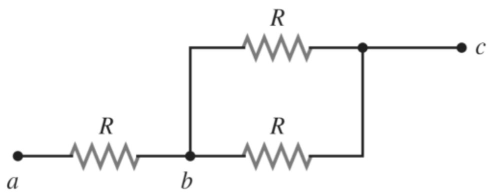
6 You are working late in your electronics shop and find that you need various resistors for a project. But alas, all you have is a big box of 10Ω resistors. Show how you can make each of the following equivalent resistances by a combination of your 10Ω resistors:

a. 35Ω
b. 1Ω
c. 3.33Ω
d. 7.5Ω

7 The circuit shown in the drawing is constructed with six identical resistors and an ideal battery. When the resistor R_4 is removed from the circuit, the current in the battery decreases by 1.9A. Determine the resistance of each resistor.



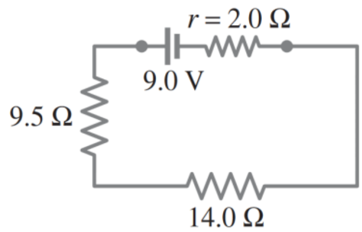
8 The circuit in the drawing contains three identical resistors. Each resistor has a value of 10.0Ω. Determine the equivalent resistance between the points a and b, b and c, and a and c.



Exercise Sheet 11: Kirchhoff's

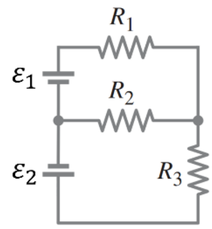
Easy

1 Calculate the current in the circuit of the figure shown, and show that the sum of all the voltage changes around the circuit is zero.

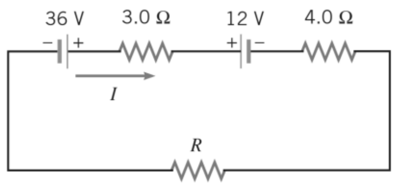


2 Determine the magnitudes and directions of the currents in each resistor shown in the figure shown. The batteries have emfs of $\varepsilon_1 = 9V$ and $\varepsilon_2 = 12V$ and the resistors have values of $R_1 = 25\Omega$, $R_2 = 68\Omega$ and $R_3 = 35\Omega$.

a. Ignore internal resistance of the batteries.
b. Assume each battery has internal resistance r = 1.0Ω.

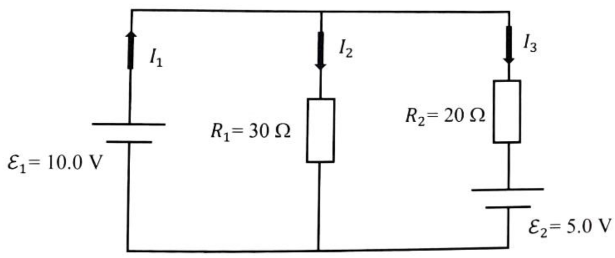


3 Using Kirchhoff's loop rule, find the value of the current I in circuit shown, where $R = 5\Omega$.



Past Year

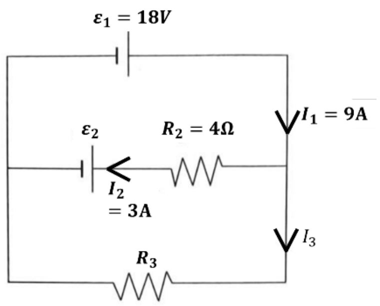
4 **PSPM 21/22 – Q3(c)**



Calculate current I_1, I_2, and I_3 as in the figure shown.

5 **PSPM 20/21 – 3(b)**

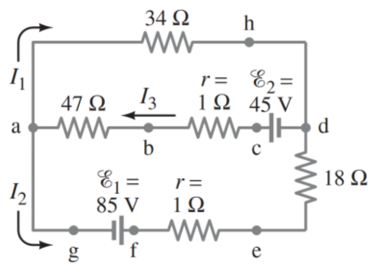
The figure shows a circuit consisting of two batteries and two resistors.



Calculate the value of I_3 and R_3.

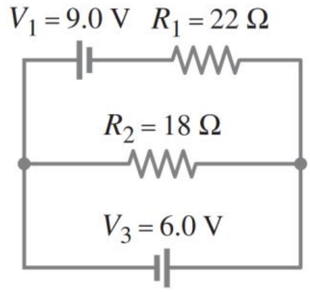
Book

6 What is the potential difference between points a and d in the figure shown. What is the terminal voltage of each battery?

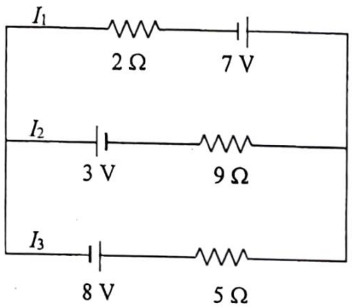
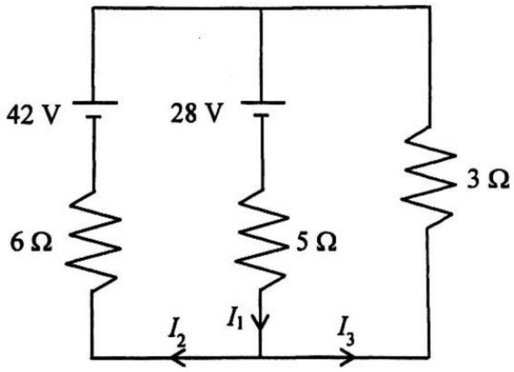
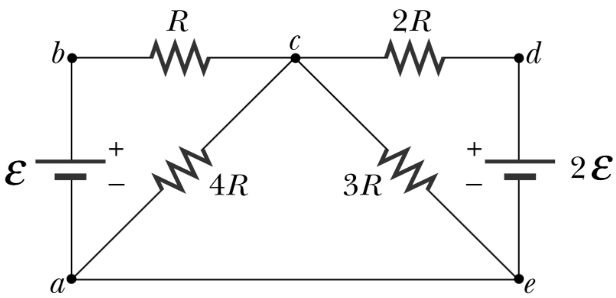
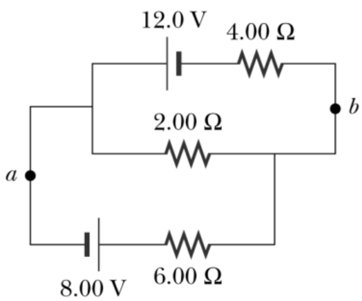


7 Determine the magnitudes and directions of the currents through R_1 and R_2 in the figure shown.

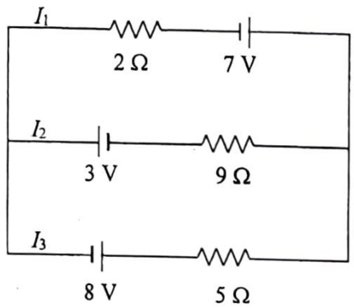
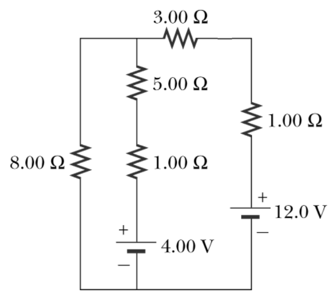
Now assuming that each battery has an internal resistance $r = 1.4\Omega$, determine the currents through R_1 and R_2.



Exercise Sheet 12: Kirchhoff's

Past Year	
1	**PSPM 19/20 – Q3**  For the circuit in the figure shown, determine the current I_1, I_2 and I_3.
2	**PSPM 17/18 – Q2(c)**  For the circuit in the figure shown, determine the current I_1, I_2 and I_3.
Book	
3	Taking $R = 1k\Omega$ and $\varepsilon = 250V$ in the figure shown, determine the direction and magnitude of the current in the horizontal wire between a and e. 
4	For the circuit shown in the figure shown, calculate a. The current in the 2Ω resistor b. the potential difference between points a and b 

Exercise Sheet 13: Electrical Energy & Power

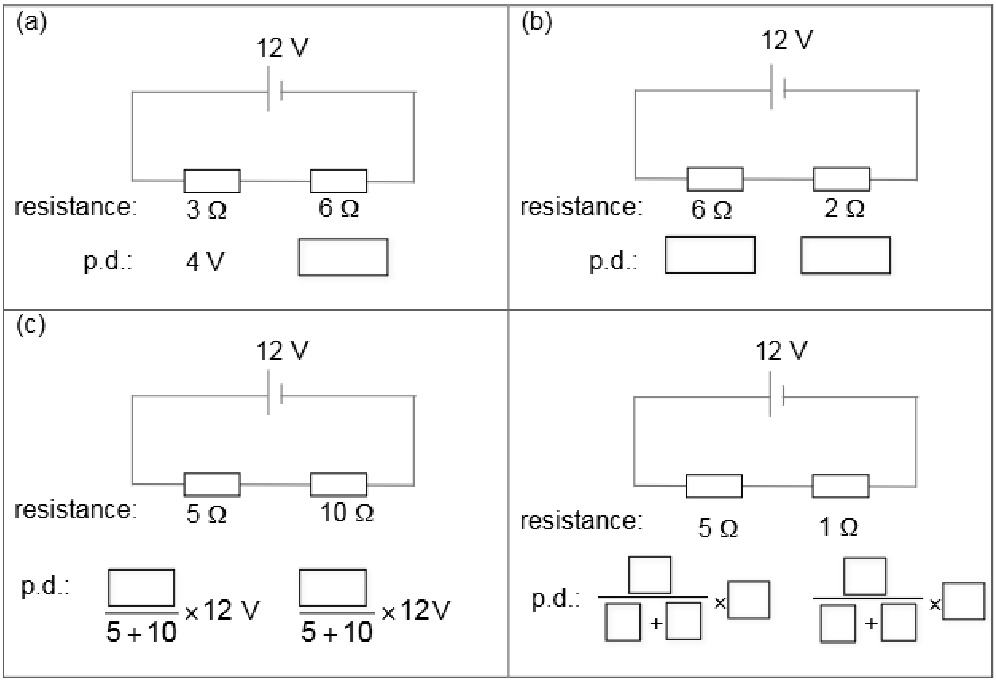
Easy	
1	An electric blanket is connected to a 120-V outlet and consumes 140 W of power. What is the resistance of the heater wire in the blanket?
2	An electric car uses a 45-kW (160-hp) motor. If the battery pack is designed for 340 V, what current would the motor need to draw from the battery? Neglect any energy losses in getting energy from the battery to the motor.
3	A 12-V battery causes a current of 600mA through a resistor. a. What is its resistance? b. How many joules of energy does the battery lose in a minute?
Past Year	
4	**PSPM 19/20 – Q3**  For the circuit in the figure shown, determine the power dissipated by the 5Ω.
5	**PSPM 18/19 – Q3(b)** A 2.5kW heater is connected to a 220V power supply. The voltage of the power supply is then changed to 110V. Calculate the power output of the heated.
6	**PSPM 17/18 – Q2(b)** The resistivity of a cooper wire is $1.72 \times 10^{-8} \Omega m$. An electric current of 2.07A flows in the wire. If the wire has a cross sectional area of $8.0 \times 10^{-7} m^2$ and length of 50 m, calculate energy dissipated in 1 minute.
Book	
7	Referring to the circuit in the figure shown, the circuit is connected for 2min. a. Find the energy delivered by each battery. b. Find the energy delivered to each resistor. c. Identify the types of energy transformations that occur in the operation of the circuit and the total amount of energy involved in each type of transformation. 
8	A power station delivers 750 kW of power at 12,000 V to a factory through wires with total resistance How much less power is wasted if the electricity is delivered at 50,000 V rather than 12,000 V?
9	You want to design a portable electric blanket that runs on a 1.5-V battery. If you use a 0.50-mm-diameter copper wire as the heating element, how long should the wire be if you want to generate 18W of heating power? What happens if you accidentally connect the blanket to a 9.0-V battery?

Exercise Sheet 14: Potential Divider & Potentiometer

Easy

1 Consider the following circuit: a cell with emf 12 V connected to two resistors in series.
Find the potential difference across each resistor.
Follow these rules:

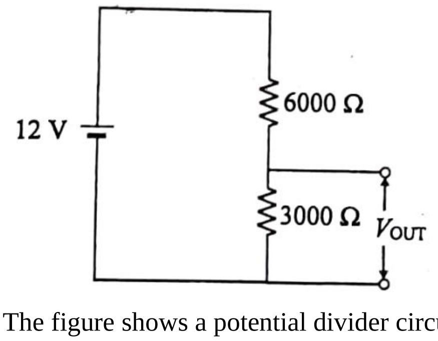
a. For resistors in series, $E = V_1 + V_2 + V_3 + \ldots$.
b. The ratio of p.d. is equal to the ratio of resistance.



2 A DC potentiometer is designed to measure up to about 2V with a slide wire of 800 mm. A standard cell of emf 1.18 V obtains balances at 600 mm. A test cell is seen to obtain balance at 680 mm. Calculate the emf of the test cell.

Past Year

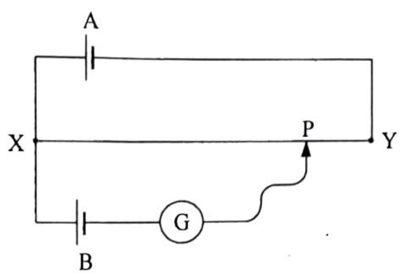
3 **PSPM 19/20 – Q3(b)**



The figure shows a potential divider circuit.

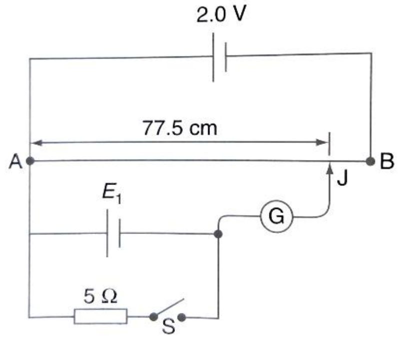
a. Calculate the output voltage.
b. If a voltmeter of resistance 3000Ω is connected across the output, determine the reading of the voltmeter.

4 **PSPM 16/17 – Q2(c)**

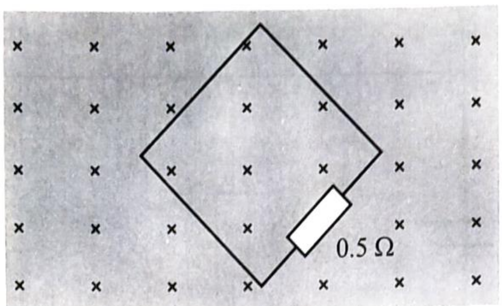
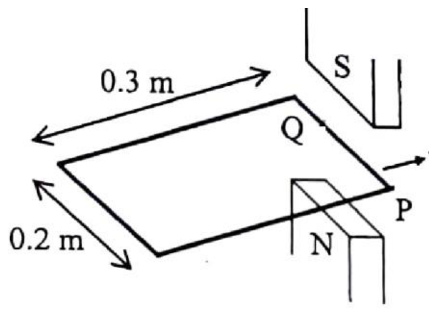
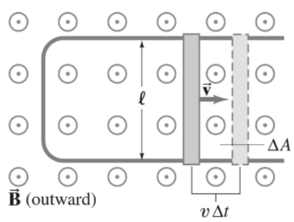


The figure shows a potentiometer circuit consists of a uniform wire XY of length 100cm and its resistance 5Ω. The emf of call A and B is 4.0V and 3.0V, respectively. The internal resistance of both cells are negligible.

a. What is the length of XP when the galvanometer reading is zero?
b. If a 1.0Ω is connected in series with cell A, what is the new balanced length of XP?

5	Two cylindrical rods, one copper and the other iron, are identical in lengths and cross-sectional areas. They are joined end to end to form one long rod. A 12-V battery is connected across the free ends of the copper–iron rod. The resistivity of copper and iron is $1.72 \times 10^{-8} \Omega m$ and $9.7 \times 10^{-8} \Omega m$ respectively. What is the voltage between the ends of the copper rod?
6	The emf E_1 of a cell is measured using a potentiometer as shown in the figure. The driver cell has an emf of 2V and negligible resistance. When the switch S is open, the galvanometer G is balanced when the length AJ is 77.5cm. When the switch S is closed, the length AJ is 63.8 cm. a. Calculate the emf E_1 b. Calculate the internal resistance of the cell. 

Exercise Sheet 15: Magnetic Flux & Induced Emf

Easy	
1	A plane coil of 20 turns has a cross sectional area of $0.045m^2$ is placed in a uniform magnetic field strength of 0.075T. Calculate the magnetic flux for linked with the coil if the coil area is a. parallel to the magnetic field lines b. perpendicular to the magnetic field lines. c. angled at 25^o to the magnetic field lines.
2	A plane coil of 20 turns, a cross sectional area of $0.025m^2$, experiences magnetic flux change from 0.2T to 0.5T in 3 seconds and is connected to a 2Ω resistor. Determine the induced emf and induced current.
3	A copper rod of length 0.8m moves perpendicularly through a region of 0.5T magnetic field at $2ms^{-1}$. Determine the induced emf within the rod.
4	a. 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. b. A circular coil of 20turns in a magnetic field of 0.4T changes its radius from 2cm to 5cm, determine magnitude of induced emf.
5	An AC generator consisting a 30turns coil with cross sectional area of 0.1m2 and resistance of 100Ω. The coil rotates in a magnetic field of strength 0.5T at a frequency of 30Hz. Calculate the maximum induced current.
Past Year	
6	**PSPM 21/22 – Q4(a)** The figure shows a square wire loop with 2m sides, connect to a 0.5Ω resistor placed perpendicularly to a changing magnetic field. a. If the magnetic field changes uniformly from 0 to 0.4T in 6.0s, calculate the induced emf in the loop. b. Determine the current induced in the loop and its direction. Explain your answer. 
7	**PSPM 20/21 – Q4(a)** A 14 turns circular coil is placed on a paper which lies in 1.2T magnetic field pointing inwards to the paper. The coil's diameter changes from 22.5cm to 7.2cm in 1.8s. a. Determine the direction of the induced current. b. Calculate the magnitude of the emf induced in the circuit. c. Calculate the induced current if the circular coil resistance is 7.5Ω.
8	**PSPM 19/20 – Q4(a)** The figure shows a rectangular wire loop $0.3m \times 0.2m$ moving horizontally to the right at $12ms^{-1}$ in a uniform magnetic field of 0.8T. The induced current in the wire is 3A. a. Determine the resistance of the wire loop. b. Determine the direction of the induced current. Explain how you determine the direction of the induced current. 
Book	
9	Referring to the figure shown, the moving rod has a resistance of 0.25Ω and moves on rails 20cm apart. The stationary U-shaped conductor has negligible resistance. When a force of 0.35N is applied to the rod, it moves to the right at a constant speed of $1.5ms^{-1}$. What is the magnetic field? 

10 The magnetic field perpendicular to a single 13.2cm diameter circular loop of copper wire decreases uniformly from 0.670 T to zero. If the wire is 2.25 mm in diameter, how much charge moves past a point in the coil during this operation?

11 Use Lenz's law to answer the following questions concerning the direction of induced currents.

a. What is the direction of the induced current in resistor R in figure 1 when the bar magnet is moved to the left?
b. What is the direction of the current induced in the resistor R immediately after the switch S in figure 2 is closed?
c. What is the direction of the induced current in R when the current I in figure 3 decreases rapidly to zero?
d. A copper bar is moved to the right while its axis is maintained in a direction perpendicular to a magnetic field, as shown in figure 4. If the top of the bar becomes positive relative to the bottom, what is the direction of the magnetic field?

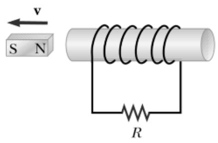


Figure 1

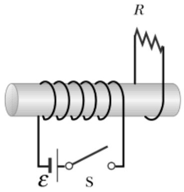


Figure 2

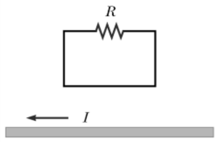


Figure 3

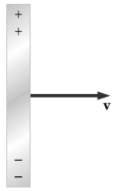
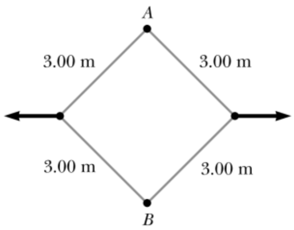
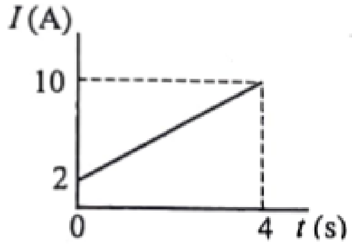
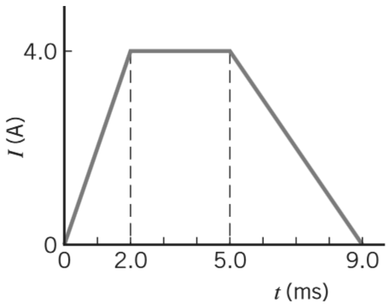


Figure 4

12 The square loop in the figure shown is made of wires with total series resistance 10Ω. It is placed in a uniform 0.1T magnetic field directed perpendicularly into the plane of the paper. The loop, which is hinged at each corner, is pulled as shown until the separation between points A and B is 3.00 m. If this process takes 0.1s, what is the average current generated in the loop? What is the direction of the current?



Exercise Sheet 16: Self-Inductance, Energy Storage & Mutual Inductance

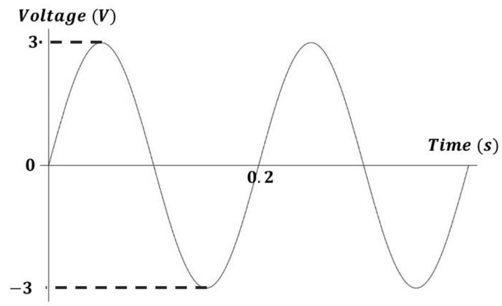
Easy	
1	Induced emf of 6V is developed across a coil when the current flowing through it changes at $30As^{-1}$. Determine the self-inductance of the coil.
2	Calculate the value of self-inductance for an air-filled solenoid of length 5cm and cross-sectional area of 0.3cm2 containing 50 loops.
3	A 500turns 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.
Past Year	
4	**PSPM 21/22 – Q4(b)** A 50cm long solenoid S_1 with 1000 turns, diameter 0.5cm, experiences an induced emf of 3.0mV and a changing current of $5As^{-1}$. a. Determine the self-inductance of the solenoid S_1. b. A second coil S_2 with 150 turns is wound coaxially around solenoid S_1. Calculate the mutual inductance of the combination of two coils.
5	**PSPM 20/21 – Q4(b)** A circular coil of N turns with current 9.4 mA has an inductance 15mH. Calculate the a. magnetic flux linkage through the coil b. radius of the coil if N = 420turns
6	**PSPM 19/20 – Q4(b)** A 6cm long solenoid with 400 turns and cross sectional area $7 \times 10^{-4} m^2$ experiences a changing current as shown in the figure. Determine the a. induced emf b. magnetic flux through each turn **and** the stored enery at the instant when the current is 3A. 
Book	
7	The current through a 3.2-mH inductor varies with time according to the graph shown in the drawing. What is the average induced emf during the time intervals a. 0–2.0ms, b. 2.0–5.0ms, c. 5.0–9.0ms? 
8	A solenoid has 120 turns uniformly wrapped around a wooden core, which has a diameter of 10.0 mm and a length of 9.00 cm. a. Calculate the inductance of the solenoid. b. The wooden core is replaced with a soft iron rod that has the same dimensions, but a magnetic permeability $\mu_m = 800\mu_0$.What is the new inductance?
9	A long, current-carrying solenoid with an air core has 1750 turns per meter of length and a radius of 0.0180 m. A coil of 125 turns is wrapped tightly around the outside of the solenoid, so it has virtually the same radius as the solenoid. What is the mutual inductance of this system?
10	A 54μH solenoid is constructed by wrapping 65 turns of wire around a cylinder with a cross-sectional area of $9 \times 10^{-4} m^2$ When the solenoid is shortened by squeezing the turns closer together, the inductance increases to $86\mu H$. Determine the change in the length of the solenoid.

Exercise Sheet 17: RLC Circuits

Easy

1 The voltage generated by a generator is as shown in the graph.

a. What is the peak voltage, peak-to-peak voltage and the rms voltage?
b. The voltage is connected across a resistor with a resistance 2.5Ω. Calculate the peak, rms current and average power.



2 A voltage V = 60sin120πt is applied across a 20Ω resistor. Calculate the reading on the ac ammeter and the average power.

3 A circuit has a resistance of 11Ω, a coil of inductive reactance 120Ω and a capacitor of 100Ω, all connected in series with 110V, 60Hz power source. What is the potential difference across each circuit element.

Past Year

4 **PSPM 21/22 – Q5**

A 160Ω resistor, 230mH inductor and $70\mu F$ capacitor are connected in series across 36V, 60Hz AC source. Calculate the impedance, maximum current, phase angle between the current and voltage, the power factor and the power loss.

Is the circuit in resonance? Explain your answer.

5 **PSPM 20/21 – Q4(b)**

a. A series RLC circuit attached to a power supply of peak voltage 140 V with a power factor of 0.76.
Given

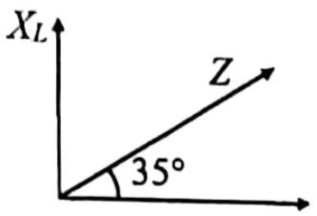
$$I = 4.5 \sin 20\pi t$$

where I in A and t in s.
   i. Calculate the rms current in the circuit.
   ii. Calculate the value of resistance.
   iii. Determine the impedance.

b. An inductor is connected in series to an AC voltage supply of 30V and frequency 60Hz. Inductive reactance of the inductor is 98Ω. Calculate the
   i. Inductance
   ii. Peak current

6 **PSPM 19/20 – Q5**

The figure shows a phasor diagram of an RL series circuit connected to an AC source with rms voltage across the inductor of 62.8V at 50Hz, 0.8H inductor and an unknown resistor.

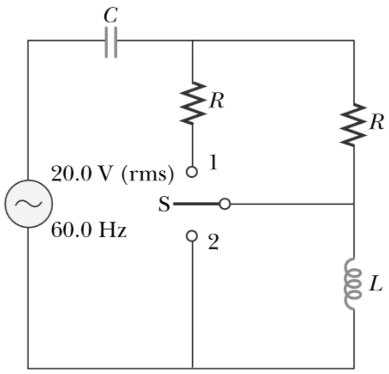


a. Determine the
   i) Resistance of the resistor
   ii) Peak voltage of the AC source
   iii) Average power

b. If the resistor is removed from the circuit, draw the variation of current and voltage against time on the same labelled graph.

Book

7 A generator is connected to a resistor and a 0.032-H inductor in series. The rms voltage across the generator is 8.0 V. When the generator frequency is set to 130 Hz, the rms voltage across the inductor is 2.6 V. Determine the resistance of the resistor in this circuit.

8	A capacitor, a coil, and two resistors of equal resistance are arranged in an AC circuit, as shown in the figure. An AC source provides an emf of 20.0 V (rms) at a frequency of 60.0 Hz. When the double-throw switch S is open, as shown in the figure, the rms current is 183 mA. When the switch is closed in position 1, the rms current is 298 mA. When the switch is closed in position 2, the rms current is 137 mA. Determine the values of R, C, and L. Is more than one set of values possible?	
9	A resonant circuit using a 260-nF capacitor is to resonate at 18.0 kHz. The air-core inductor is to be a solenoid with closely packed coils made from 12.0 m of insulated wire 1.1 mm in diameter. How many loops will the inductor contain?	
10	In an RC circuit, $R = 6.6k\Omega, C = 1.8\mu F$, and the rms applied voltage is 120 V at 60.0 Hz? a. What is the rms current in the RC circuit? b. What is the phase angle between voltage and current? c. What are the voltmeter readings across R and C?	

Additional Notes & Exercise: Sign Conventions in Geometrical Optics

Reflection at a spherical surface

From CS:

LO: Use mirror equation, $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ for real object only. Sign convention for focal length, *f* and radius of curvature, *R:* i. Positive *f* and *R* for concave mirror; and ii. Negative *f* and *R* for convex mirror.

From Serway:

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

$$M = \frac{h'}{h} = -\frac{q}{p}$$

Table 36.1

Sign Conventions for Mirrors

Quantity	Positive When	Negative When
Object location (p)	Object is in front of mirror (real object)	Object is in back of mirror (virtual object)
Image location (q)	Image is in front of mirror (real image)	Image is in back of mirror (virtual image)
Image height (h')	Image is upright	Image is inverted
Focal length (f) and radius (R)	Mirror is concave	Mirror is convex
Magnification (M)	Image is upright	Image is inverted

From Cutnell:

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$M = \frac{h'}{h} = -\frac{d_i}{d_o}$$

Reasoning Strategy Summary of Sign Conventions for Spherical Mirrors

Focal length

f is + for a concave mirror.
f is − for a convex mirror.

Object distance

d_o is + if the object is in front of the mirror (real object).
d_o is − if the object is behind the mirror (virtual object).*

Image distance

d_i is + if the image is in front of the mirror (real image).
d_i is − if the image is behind the mirror (virtual image).

Magnification

m is + for an image that is upright with respect to the object.
m is − for an image that is inverted with respect to the object.

*Sometimes optical systems use two (or more) mirrors, and the image formed by the first mirror serves as the object for the second mirror. Occasionally, such an object falls *behind* the second mirror. In this case the object distance is negative, and the object is said to be a virtual object.

From geeksforgeeks.org:

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

The sign conventions followed for any spherical mirror are given as:

- *All distances are measured from the pole of a spherical error.*
- *Distances measured in the direction of incident light are taken as positive, while distances measured in a direction opposite to the direction of the incident light are taken as negative.*
- *The upward distances perpendicular to the principal axis are taken as positive, while the downward distances perpendicular to the principal axis is taken as negative.*
  - *For convenience, the object is assumed to be placed on the left side of a mirror. Hence, the distance of an object from the pole of a spherical mirror is taken as negative.*
  - *Since the incident light always goes from left to right, all the distances measured from the pole (P) of the mirror to the right side will be considered positive (because they will be in the same directions as the incident light). On the other hand, all the distances measured from pole (P) of the mirror to the left will be negative (because they are measured against the direction of incident light)*

Refraction at a spherical surfaces

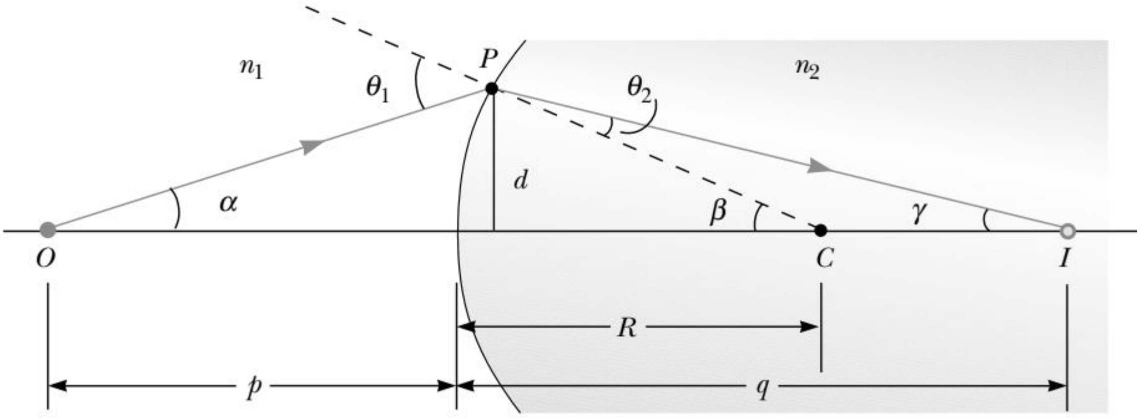


Figure 36.19 Geometry used to derive Equation 36.8, assuming that $n_1 < n_2$.

Snell's Law:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

Small angle approximation:

$$\sin\theta_i \approx \theta_i \Rightarrow n_1\theta_1 = n_2\theta_2$$

Exterior angle of any triangle is the sum of two opposite interior angles,

$$\theta_1 = \alpha + \beta;\ \beta = \theta_2 + \gamma$$

Eliminate θ_1 and θ_2,

$$n_1(\alpha + \beta) = n_2(\beta - \gamma)$$

Based on diagram, common vertical leg is *d*,

$$\tan\alpha \approx \alpha \approx \left(\frac{d}{p}\right);\ \tan\beta \approx \beta \approx \left(\frac{d}{R}\right);\ \tan\gamma \approx \gamma \approx \left(\frac{d}{q}\right)$$

Rearranging terms yields,

$$n_1\left(\frac{d}{p} + \frac{d}{R}\right) = n_2\left(\frac{d}{R} - \frac{d}{q}\right)$$

Cancelling *d* on both sides and rearranging the terms yields,

$$\frac{n_1}{p} + \frac{n_2}{q} = \frac{n_2 - n_1}{R}$$

Sign Conventions

From CS:

LO: Use $\frac{n_1}{u} + \frac{n_2}{v} = \frac{n_2 - n_1}{R}$ for spherical surface.
Sign convention for radius of curvature, *R:*
i. Positive *R* for convex surface; and
ii. Negative *R* for concave surface.

From Serway:

$$\frac{n_1}{p} + \frac{n_2}{q} = \frac{n_2 - n_1}{R}$$

Table 36.2

Sign Conventions for Refracting Surfaces

Quantity	Positive When	Negative When
Object location (p)	Object is in front of surface (real object)	Object is in back of surface (virtual object)
Image location (q)	Image is in back of surface (real image)	Image is in front of surface (virtual image)
Image height (h')	Image is upright	Image is inverted
Radius (R)	Center of curvature is in back of surface	Center of curvature is in front of surface

Thin Lenses

LO:

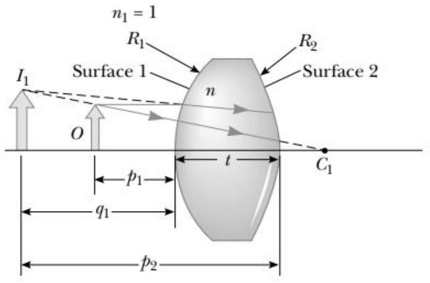
a. Use thin lenses equation, $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ for real object only.
   Sign convention for focal length:
   i. Positive f for convex mirror; and
   ii. Negative f for concave mirror.

b. Use lensmaker's equation, $\frac{1}{f} = \left(\frac{n_{material}}{n_{medium}} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

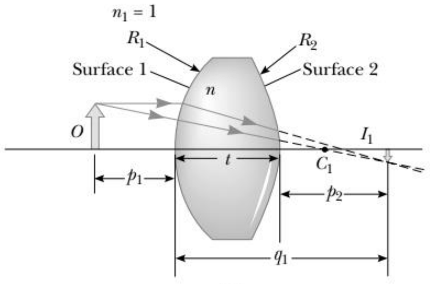
c. Apply magnification, $M = \frac{h_i}{h_o} = -\frac{v}{u}$

d. Use thin lens equation for a combination of two convex lenses.

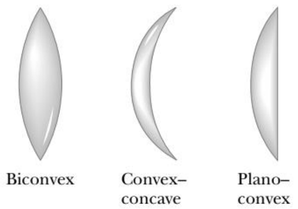
From Serway (adapted):



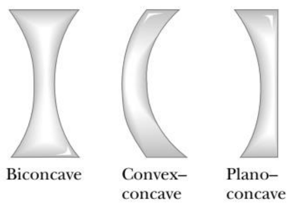
(a)



(b)



(a)



Consider image formed by surface 1,

$$\frac{n_{medium}}{p_1} + \frac{n_{lens}}{q_1} = \frac{n_{lens} - n_{medium}}{R_1}$$

We can then apply this to surface 2,

$$\frac{n_{lens}}{p_2} + \frac{n_{medium}}{q_2} = \frac{n_{medium} - n_{lens}}{R_2}$$

Using the image from surface 1 as the object for surface 2,

$$p_2 = -q_1 + t$$

Where t is the thickness of the lens and is ≈ 0 for thin lenses ($t \ll R$).

$$\frac{n_{lens}}{-q_1} + \frac{n_{medium}}{q_2} = \frac{n_{medium} - n_{lens}}{R_2}$$

$$\frac{1}{f} = \frac{1}{p_1} + \frac{1}{q_2} = \left(\frac{n_{lens}}{n_{medium}} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Table 36.3

Sign Conventions for Thin Lenses

Quantity	Positive When	Negative When
Object location (p)	Object is in front of lens (real object)	Object is in back of lens (virtual object)
Image location (q)	Image is in back of lens (real image)	Image is in front of lens (virtual image)
Image height (h')	Image is upright	Image is inverted
R_1 and R_2	Center of curvature is in back of lens	Center of curvature is in front of lens
Focal length (f)	Converging lens	Diverging lens

From Cutnell:

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

Reasoning Strategy Summary of Sign Conventions for Lenses

Focal length

f is + for a converging lens.
f is − for a diverging lens.

Object distance

d_o is + if the object is to the left of the lens (real object), as is usual.
d_o is − if the object is to the right of the lens (virtual object).*

Image distance

d_i is + for an image (real) formed to the right of the lens by a real object.
d_i is − for an image (virtual) formed to the left of the lens by a real object.

Magnification

m is + for an image that is upright with respect to the object.
m is − for an image that is inverted with respect to the object.

*This situation arises in systems containing more than one lens, where the image formed by the first lens becomes the object for the second lens. In such a case, the object of the second lens may lie to the right of that lens, in which event d_o is assigned a negative value and the object is called a virtual object.

From Giancoli:

$$\frac{1}{f}=\frac{1}{d_o}+\frac{1}{d_i}$$ $$m=\frac{h_i}{h_o}=-\frac{d_i}{d_o}$$	**sign conventions**: **1.** The focal length is positive for converging lenses and negative for diverging lenses. **2.** The object distance is positive if the object is on the side of the lens from which the light is coming (this is always the case for real objects; but when lenses are used in combination, it might not be so: see Example 23–16); otherwise, it is negative. **3.** The image distance is positive if the image is on the opposite side of the lens from where the light is coming; if it is on the same side, d_i is negative. Equivalently, the image distance is positive for a real image (Fig. 23–40) and negative for a virtual image (Fig. 23–41). **4.** The height of the image, h_i, is positive if the image is upright, and negative if the image is inverted relative to the object. (h_o is always taken as upright and positive.)

<u>Thin lens equation for two convex lenses</u>

From Giancoli:

"When light passes through more than one lens, we find the image formed by the first lens as if it were alone. Then this image becomes the object for the second lens. Next we find the image formed by this second lens using the first image as object. This second image is the final image if there are only two lenses. The total magnification will be the product of the separate magnifications of each lens."

<u>Example from Giancoli:</u>

Problem

Two converging lenses, A and B, with focal lengths $f_A = 20cm$ and $f_B = 25cm$ and are placed 80.0 cm apart, as shown

in Fig. 23–44a. An object is placed 60.0 cm in front of the first lens as shown in Fig. 23–44b.

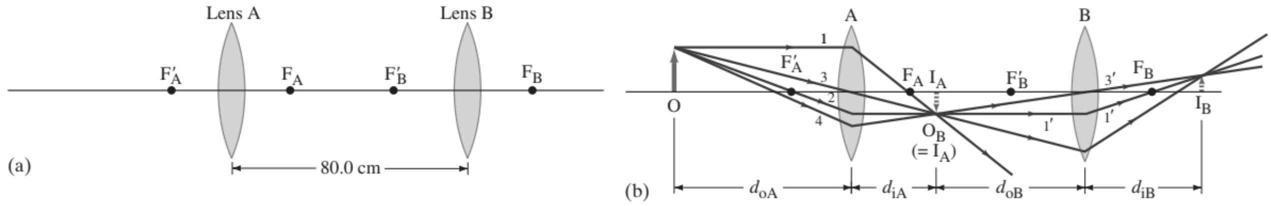


FIGURE 23–44

Determine (a) the position, and (b) the magnification, of the final image formed by the combination of the two lenses

Solutions

Position:

$$\frac{1}{d_{iA}}=\frac{1}{f_A}-\frac{1}{d_{oA}} \Rightarrow d_{iA}=\frac{f_A d_{oA}}{d_{oA}-f_A}$$
$$\frac{1}{d_{iB}}=\frac{1}{f_B}-\frac{1}{d_{oB}} \Rightarrow d_{iB}=\frac{f_B d_{oB}}{d_{oB}-f_B}$$
$$80cm = d_{iA}+d_{oB} \Rightarrow d_{oB}=80cm-d_{iA}$$
$$d_{iB}=\frac{f_B(80cm-d_{iA})}{(80cm-d_{iA})-f_B}=\frac{f_B\left(80cm-\left(\frac{f_A d_{oA}}{d_{oA}-f_A}\right)\right)}{\left(80cm-\left(\frac{f_A d_{oA}}{d_{oA}-f_A}\right)\right)-f_B}=\frac{(25)\left(80cm-\left(\frac{(20)(60)}{60-20}\right)\right)}{\left(80cm-\left(\frac{(20)(60)}{60-20}\right)\right)-25}=50cm$$

⇒Final image is formed 50cm behind lens B.

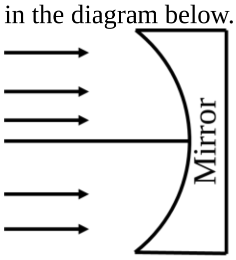
Total Magnification:

$$M_T = M_1 M_2 = \left(-\frac{d_{iA}}{d_{oA}}\right)\left(-\frac{d_{iB}}{d_{oB}}\right)=\left(-\frac{30}{60}\right)\left(-\frac{50}{50}\right)=\frac{1}{2}$$

⇒Final image is upright and half of the original object height.

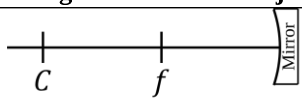
Exercise

Geometrical Optics: Reflection

$R = 2f$	Find R	a.	A spherical mirror of diameter 2cm is illuminated with parallel light rays as shown in the diagram below.  Determine the radius of curvature of the spherical mirror. $\boldsymbol{[R = 1cm]}$
	Find f	b.	Based on question (a), determine the point at which the light rays would converge at. $\boldsymbol{[f = 0.5cm]}$
$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$	Concave	c.	An object is placed 3cm **in front of** a mirror. The image is found to form 6cm **in front of** the mirror. Determine the focal length of the mirror. $\boldsymbol{[f = 2cm]}$
	Convex	d.	An object is placed 6cm **in front of** a mirror. The image is found to form 3cm **behind** the mirror. Determine the focal length of the mirror. $\boldsymbol{[f = -6cm]}$
	Real Object	e.	An object is placed $x\ cm$ from a convex mirror. The image is found to form 3cm **behind** the mirror and the focal length of the mirror is 9cm. Determine the object distance from the mirror. $\boldsymbol{[u = 4.5cm]}$
		f.	An object is placed in front of a concave mirror. The image is found to form 3cm **in front of** the mirror and the focal length of the mirror is 2cm. Determine the object distance from the mirror. $\boldsymbol{[u = 6cm]}$
	Real Image	g.	An object is placed 4cm in front of a concave mirror. The focal length of the mirror is 2cm. Determine the image distance from the mirror. $\boldsymbol{[v = 4cm]}$
	Virtual Image	h.	An object is placed 4cm in front of a convex mirror. The focal length of the mirror is 4cm. Determine the image distance from the mirror. $\boldsymbol{[v = 2cm]}$
$M = \frac{h_i}{h_o}$	Magnified	i.	The virtual image of a real object from a spherical mirror is found to form at $4cm$ when the object is placed $2cm$ from the mirror. Determine the magnification. $\boldsymbol{[M = 2]}$
$M = -\frac{v}{u}$	Diminished	j.	An object is placed 2cm in front of a convex mirror of focal length 6cm. Determine the image distance and the magnification. [$\boldsymbol{v = -1.5cm}$; $\boldsymbol{M = 0.75}$]

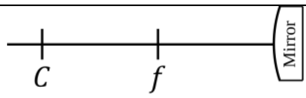
Properties of image based on real object position and type of mirror

Concave



		u (cm)	V (cm)	M
$f = 4cm$	$u < f$	2		
	$C > u > f$	6		
	$u > C$	12		

Convex



		u (cm)	V (cm)	M
$f = -4cm$	$u < f$	2		
	$C > u > f$	6		
	$u > C$	12		

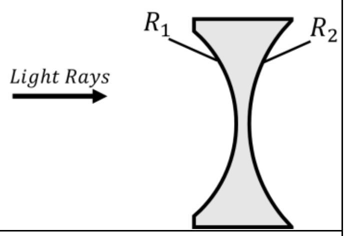
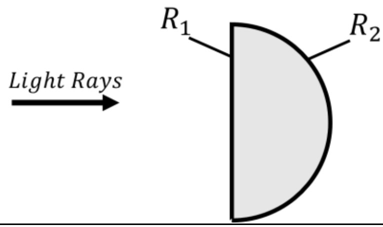
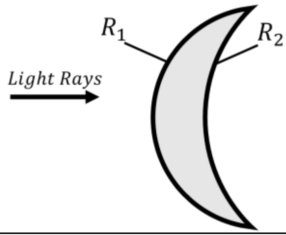
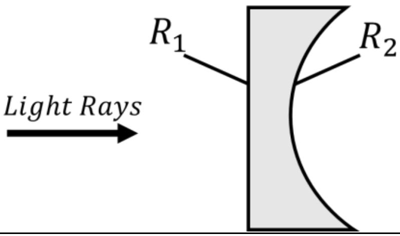
Geometrical Optics: Refraction

$\frac{n_1}{u}+\frac{n_2}{v}=\frac{n_2-n_1}{R}$	Real Object	a.	When an object is placed some distance from a convex interface of a material of radius $2cm$, an image of the object is formed 4cm **behind** the interface. If the refractive index before and after the material is 1.2 and 3.4 respectively, determine the **object distance** from the interface. $[\boldsymbol{u=4.8cm}]$
	Virtual Object	b.	When an object is placed some distance from a convex interface of a material of radius $2cm$, an image of the object is formed 0.5cm **behind** the interface. If the refractive index before and after the material is 1.2 and 3.4 respectively, determine the **object distance** from the interface. $[\boldsymbol{u\approx -0.21cm}]$
	Real Image	c.	An object is placed 20cm from a **convex interface** of a material of radius $2cm$. If the refractive index before and after the material is 1.2 and 3.4 respectively, determine the image distance from the interface. $[\mathbf{v}\approx \boldsymbol{3.27cm}]$
	Virtual Image	d.	An object is placed 20cm from a **concave interface** of a material of radius $2cm$. If the refractive index before and after the material is 1.2 and 3.4 respectively, determine the image distance from the interface. $[\boldsymbol{v\approx -2.93cm}]$
	Convex Surface	e.	An object is placed 24cm **in front of** an interface of a material of refractive index of 2.8. The refractive index before the interface is 1.3. If the image is found to form 56cm **behind** the interface, determine the radius of curvature of the interface. $[R=14.4cm]$
	Concave Surface	f.	An object is placed 24cm **in front of** an interface of a material of refractive index of 2.8. The refractive index before the interface is 1.3. If the image is found to form 18cm **in front of** the interface, determine the radius of curvature of the interface. $[R=-14.2cm]$
	Refractive index before interface	g.	An object is placed 25cm **in front of** an interface of a material of refractive index of 3.3. If the image is found to form 18cm **behind** the interface, determine the refractive index of the material before the interface. $[n_1\approx 1.39]$
	Refractive index after interface	h.	An object is placed 24cm **in front of** a convex interface of a material of refractive index of n. The refractive index before the interface is 1.4. If the image is found to form 38cm behind the interface and the radius of curvature of the interface is 15cm, determine the refractive index n. $[n\approx 3.88]$

Geometrical Optics: Thin lenses

$\frac{1}{f}=\frac{1}{u}+\frac{1}{v}$; $\frac{1}{f}=\left(\frac{n_{material}}{n_{medium}}-1\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$; $M=\frac{h_i}{h_o}=-\frac{v}{u}$

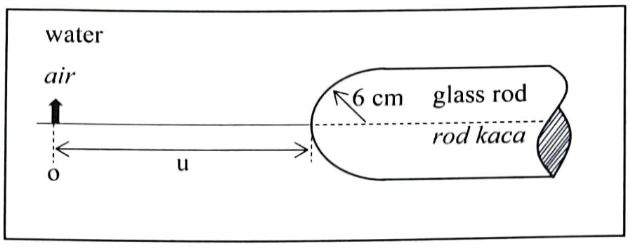
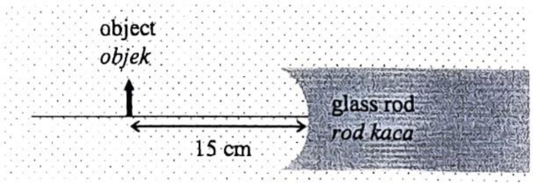
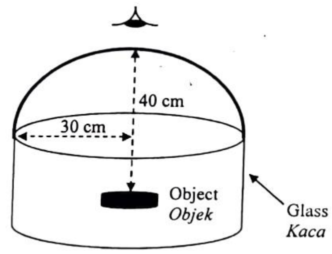
$\frac{1}{f}=\frac{1}{u}+\frac{1}{v}$	Diverging (Concave)	a.	When placed 4cm in front of a thin lens, the image of an object forms 2.4cm **in front of** the lens. Determine the focal length of the lens. $[\boldsymbol{f=-6cm}]$
	Converging (Convex)	b.	When placed 4cm in front of a thin lens, the image of an object forms 2.4cm **behind** the lens. Determine the focal length of the lens. $[\boldsymbol{f=1.5cm}]$
	Real Object	c.	An object placed in front of a lens of focal length 2cm forms an image 3cm **behind** the lens. Determine the object distance from the lens. $[\boldsymbol{u=6cm}]$
	Real Image	d.	Determine the image distance when an object is placed 12cm in front of a biconvex lens of focal length 6cm. $[\boldsymbol{v=12cm}]$
	Virtual Image	e.	Determine the image distance when an object is placed 4cm in front of a biconcave lens of focal length 6cm. $[\boldsymbol{v=-2.4cm}]$

$\frac{1}{f} = \left(\frac{n_{material}}{n_{medium}} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$	
Converging	a. A biconvex thin lens (made up of a material of refractive index 1.65) is submerged in water of refractive index 1.33. The thin lens has radius of curvature of $R_2 = 2cm$ and $R_1 = 4cm$. Determine the focal length of the thin lens. [$\boldsymbol{f = 5.54cm}$]
Diverging	b. A biconvex thin lens (made up of a material of refractive index 1.65) is submerged in water of refractive index 1.33. The thin lens has radius of curvature of $R_1 = 2cm$ and $R_2 = 4cm$. Determine the focal length of the thin lens. [$\boldsymbol{f = -5.54cm}$]
R_1	c. The diagram shows a biconcave converging lens of focal length $15cm$, made up of a material of refractive index 1.44, placed in air. If surface R_2 of the lens has a radius of curvature of 12cm, what is the radius of curvature of surface R_1? [$\boldsymbol{f = 4.258cm}$] 
R_2	d. A plano-convex lens, as shown in the diagram, has a focal length of –12cm. The lens is made up of a material of refractive index 1.47 and is placed in air. determine radius of curvature of R_2. [$\boldsymbol{R_2 = 5.64cm}$] 
$n_{material}$	e. A convex-concave lens of focal length +35cm is placed in water. If the radii of its surfaces are $R_1 = 4cm$ and $R_2 = 7cm$, determine the refractive index of the lens material. [$n_{material} = 1.684$] 
n_{medium}	f. A plano-concave lens of focal length +35cm (made up of a material of refractive index 1.65) is placed in a medium of unknown refractive index. If the radius of its surface is $R_2 = 7cm$, determine the refractive index of the medium the lens is in. [$n_{medium} = 2.063$] 

Exercise Sheet 18: Optics – Reflection

Easy	
1	An object 200cm from the vertex of a spherical concave mirror is imaged 400cm in front of the mirror, what is the radius length of the mirror?
2	An object 10cm high is 50cm from a concave mirror of 20cm focal length. Find the image distance, height and direction.
3	How far should an object be from a concave spherical mirror of radius 45cm to form a real image one-ninth of its size?
Past Year	
4	**PSPM 21/22 – Q6 (a)** An object is placed 5cm from a curved mirror. An image which is twice the size of the object is formed behind the mirror. a. Is the mirror convex or concave? Explain your answer. b. Determine the radius of curvature of the mirror.
5	**PSPM 18/19 – Q6(a)** An external side mirror of a car is convex with a radius of curvature 18m. Determine the location of the image for an object 10 m from the mirror
6	**PSPM 17/18 – Q6(b)** An object is placed in front of a concave mirror with 25cm radius of curvature. A real image twice the size of the object is formed. a. Sketch a ray diagram to illustrate the formation of the image. b. Determine the object distance from the mirror.
Book	
7	A concave mirror has a focal length of 30cm. The distance between an object and its image is 45cm. Find the object and image distances, assuming that a. the object lies beyond the centre of curvature b. the object lies between the focal point and the mirror.
8	An object 10cm tall is placed at the zero mark of a meter stick. A spherical mirror located at some point on the meter stick creates an image of the object that is upright, 4cm tall, and located at the 42cm mark of the meter stick. a. Is the mirror convex or concave? b. Where is the mirror? c. What is the mirror's focal length?
9	A shaving or makeup mirror is designed to magnify your face by a factor of 1.40 when your face is placed 20cm in front of it. a. What type of mirror is it? b. Describe the type of image that it makes of your face. c. Calculate the required radius of curvature for the mirror.

Exercise Sheet 19: Optics – Refraction

Easy	
1	The left end of a long glass rod 6.00 cm in diameter has a convex hemispherical surface 3.00 cm in radius. The refractive index of the glass is 1.60. Determine the position of the image if an object is placed in air on the axis of the rod at the following distances to the left of the vertex of the curved end: (a) infinitely far; (b) 12.0 cm; (c) 2.00 cm.
2	The glass rod of question 1 is immersed in oil (n = 1.452). An object placed to the left of the rod on the rod's axis is to be imaged 1.20 m inside the rod. How far from the left end of the rod must the object be located to form the image?
Past Year	
4	**PSPM 21/22 – Q6(b)** The figure shows a long rod with a convex surface of radius of curvature 6.0 cm at one end and is made from glass with refractive index of1.60. The glass rod is placed in water with refractive index, n = 1.33. An object placed along the rod's axis is to be imaged 53 cm inside the rod. Calculate the object position. 
5	**PSPM 19/20 – Q6(c)** The figure shows an object and a glass rod immersed in a liquid. The rod has a refractive index of 1.7 and radius of curvature 8cm. If the object distance is 15cm and the virtual image distance is 13cm, determine the refractive index of liquid. 
6	**PSPM 17/18 – Q6(b)** The figure shows an object embedded in a solid glass with a hemispherical end of radius 30cm and refractive index 1.50. The object is 40cm inside the glass. Calculate the image distance. Refractive index of air is 1. 
Book	
7	A transparent sphere of unknown composition is observed to form an image of the Sun on the surface of the sphere opposite the Sun. What is the refractive index of the sphere material?
8	One end of a long glass rod (n = 1.50) is formed into a convex surface with a radius of curvature of 6.00 cm. An object is located in air along the axis of the rod. Find the image positions corresponding to object distances of (a) 20.0 cm, (b) 10.0 cm, and (c) 3.00 cm from the end of the rod.
9	A simple model of the human eye ignores its lens entirely. Most of what the eye does to light happens at the outer surface of the transparent cornea. Assume that this surface has a radius of curvature of 6.00 mm, and assume that the eyeball contains just one fluid with a refractive index of 1.40. Prove that a very distant object will be imaged on the retina, 21.0 mm behind the cornea. Describe the image.

Exercise Sheet 20: Optics – Thin Lenses

Easy	
1	An insect 3.75 mm tall is placed 25.0 cm to the left of a thin planoconvex lens. The left surface of this lens is flat, the right surface has a radius of curvature of magnitude 12.9 cm, and the index of refraction of the lens material is 1.70. a. Calculate the location and size of the image this lens forms of the insect. Is it real or virtual? Erect or inverted? b. Repeat part (a) if the lens is reversed.
2	A lens forms an image of an object. The object is 16.0 cm from the lens. The image is 12.0 cm from the lens on the same side as the object. a. What is the focal length of the lens? Is the lens converging or diverging? b. If the object is 8.50 mm tall, how tall is the image? Is it erect or inverted?
3	A converging lens with a focal length of 70.0 cm forms an image of a 3.20-cm-tall real object that is to the left of the lens. The image is 4.50 cm tall and inverted. Where are the object and image located in relation to the lens? Is the image real or virtual?
Past Year	
4	**PSPM 21/22 – Q6(c)** A converging meniscus lens is made from a glass of refractive index 1.52 having a radius 7cm and 4cm. An object is placed 24cm in front of the lens. a. Calculate the position of the image from the lens. If the image magnified or diminished in size? Justify your answer.
5	**PSPM 20/21 – Q6** A. An orange is placed 25.2cm in front of a diverging lens with a focal length of 18cm. a. Sketch the ray diagram to show the formation of the image b. Determine the image distance. c. Determine the magnification. d. Determine **two (2)** characteristics of the image B. The convex meniscus lens has a 17cm radius for the convex surface and 25cm for the concave surface. The lens is made of glass with a refractive index, $n = 1.52$ in air. Refractive index of air is 1.0. Determine the focal length of the lens.
6	**PSPM 19/20 – Q6(b)** The figure shows a lens with radii of curvature of 15cm and 50cm, made of glass with refractive index 1.55. Determine the focal length **and** type of lens. 
Book	
7	An object is placed 96.5 cm from a glass lens (n=1.52) with one concave surface of radius 22.0 cm and one convex surface of radius 18.5 cm. Where is the final image? What is the magnification?
8	A symmetric double convex lens with a focal length of 22.0 cm is to be made from glass with an index of refraction of 1.52. What should be the radius of curvature for each surface?
9	Two lenses, one converging with focal length 20.0 cm and one diverging with focal length $-10cm$ are placed 25.0 cm apart. An object is placed 60.0 cm in front of the converging lens. Determine a. the position b. magnification of the final image formed. **c.** Sketch a ray diagram for this system.

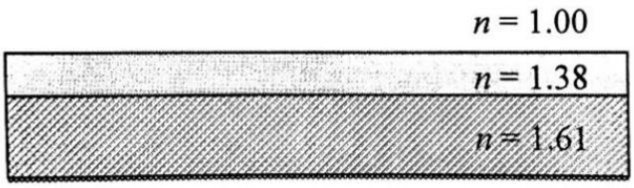
Exercise Sheet 21: Huygens' & Interferences

Easy	
1	Describe the condition for **constructive** interference.
2	Describe the condition for **destructive** interference.
Past Year	
3	**PSPM 18/19 – Q7(b)** The figure shows two paths of coherent lights from points A and B that produce an interference pattern at point C. Determine whether it is a constructive or destructive interference if AC and BC are 2.2λ and 5.7λ respectively. 
	**No other questions on Huygen’s or Interference since 2013.*
Book	
4	Two radio antennas A and B radiate in phase. Antenna B is 110 m to the right of antenna A. Consider point Q along the extension of the line connecting the antennas, a horizontal distance of 30 m to the right of antenna B. The frequency, and hence the wavelength, of the emitted waves can be varied. a. What is the longest wavelength for which there will be destructive interference at point Q? b. What is the longest wavelength for which there will be constructive interference at point Q?
5	A radio transmitting station operating at a frequency of 120 MHz has two identical antennas that radiate in phase. Antenna B is 9.00 m to the right of antenna A. Consider point P between the antennas and along the line connecting them, a horizontal distance x to the right of antenna A. For what values of x will constructive interference occur at point P?

Exercise Sheet 22: Double Slit

Easy	
1	A laser beam (λ =632.8 nm) is incident on two slits 0.200 mm apart. How far apart are the bright interference fringes on a screen 5.00 m away from the double slits?
2	Monochromatic light falling on two slits 0.018mm apart produces the fifth-order bright fringe at an 8.6° angle. What is the wavelength of the light used?
3	In a Young's double-slit experiment, the angle that locates the second dark fringe on either side of the central bright fringe is 5.4^o. Find the ratio $\frac{d}{\lambda}$of the slit separation d to the wavelength λ of the light.
Past Year	
4	**PSPM 21/22 – Q7(a)** A 475 nm light passes through two narrow slits. The interference pattern is observed on a screen at a distance 85.0 cm from the slits. The second-order bright fringe is seen at $\pm$2.01 cm from the central bright fringe. Calculate the slit separation and the width of the second-order dark fringe.
5	**PSPM 20/21 – Q7(a)** Two narrow slits separated by 2.4mm are illuminated by a light with λ= 512 nm. The screen is placed 6.5 m from the slits. Determine the a. distance between adjacent bright fringes on a screen distance of the fifth dark fringe from the central bright fringe.
6	**PSPM 19/20 – Q7(a)** In a double slit experiment, the incident wavelength is 660 nm, the slit separation is 0.25 mm, and the screen is placed 90 cm away from the sits. Calculate the distance from the second to the third destructive interference fringe.
Book	
7	Coherent light of frequency 6.32$\times$ $10^{14}Hz$ Hz passes through two thin slits and falls on a screen 85.0 cm away. You observe that the third bright fringe occurs at $\pm$3.11 cm on either side of the central bright fringe. a. How far apart are the two slits? b. At what distance from the central bright fringe will the third dark fringe occur?
8	Light of wavelength 470 nm in air shines on two slits $60\mu m$ apart. The slits are immersed in water, as is a viewing screen 40.0 cm away. How far apart are the fringes on the screen?
9	In Young's experiment a mixture of orange light (611 nm) and blue light (471 nm) shines on the double slit. The centres of the first-order bright blue fringes lie at the outer edges of a screen that is located 0.500 m away from the slits. However, the first-order bright orange fringes fall off the screen. By how much and in which direction (toward or away from the slits) should the screen be moved so that the centres of the first-order bright orange fringes will just appear on the screen?

Exercise Sheet 23: Thin Films

Easy	
1	A soap bubble (n = 1.33) is floating in air. If the thickness of the bubble wall is 115 nm, what is the wavelength of the light that is most strongly reflected?
2	An oil film (n = 1.45) floating on water is illuminated by white light at normal incidence. The film is 280 nm thick. Find a. the color of the light in the visible spectrum most strongly reflected and b. the color of the light in the spectrum most strongly transmitted. Explain your reasoning.
3	A thin film of oil (n = 1.25) is located on a smooth wet pavement. When viewed perpendicular to the pavement, the film reflects most strongly red light at 640 nm and reflects no blue light at 512 nm. How thick is the oil film?
Past Year	
4	**PSPM 21/22 – Q7(b)** A flat glass with index of refraction 1.50 is coated with a transparent material of refraction index 1.25, in order to eliminate reflection of light of wavelength 680 nm. Determine the minimum thickness of the coating.
5	**PSPM 19/20 – Q7(b)** A soap film with refractive index 1.3 and minimum thickness 0.177 μm appears reddish under white light. Calculate the wavelength of light that is missing from the reflection.
6	**PSPM 18/19 – Q7(c)** Calculate the thickness of a soap film so that a 600 nm light incident to the film would produce constructive interference. Index of refraction of soap film 1.33.
7	**PSPM 17/18 – Q6(c)** The figure shows a flint glass lens of refractive index 1.61 is coated with a thin layer film of magnesium fluoride of refractive index 1.38.  A ray of light of wavelength 565 nm is incident at right angles to the film. a. Sketch the light rays that interfere after being reflected from both surfaces of the film. Label the reflected rays that undergo phase change. b. What minimum thickness should the magnesium fluoride film have if the reflection of the 565 nm light is to appear dark? c. If a lens is used to suppress the reflection of light at high frequencies, what should be done to the thickness of the film? Explain your answer
Book	
8	A uniform thin film of alcohol (n=1.36) lies on a flat glass plate (n=1.56). When monochromatic light, whose wavelength can be changed, is incident normally, the reflected light is a minimum for $\lambda = 525nm$ and a maximum for $\lambda = 655nm$. What is the minimum thickness of the film?
9	A uniform layer of water (n=1.33) lies on a glass plate (n=1.52). Light shines perpendicularly on the layer. Because of constructive interference, the layer looks maximally bright when the wavelength of the light is 432 nm in vacuum and also when it is 648 nm in vacuum. a. Obtain the minimum thickness of the film. b. Assuming that the film has the minimum thickness and that the visible spectrum extends from 380 to 750 nm, determine the visible wavelength(s) in vacuum for which the film appears completely dark.
10	How thick (minimum) should the air layer be between two flat glass surfaces if the glass is to appear bright when 450-nm light is incident normally? What if the glass is to appear dark?

Exercise Sheet 24: Single Slit & Diffraction Grating

Easy	
1	Helium–neon laser light (λ =632.8 nm) is sent through a 0.300-mm-wide single slit. What is the width of the central maximum on a screen 1.00 m from the slit?
2	If 680-nm light falls on a slit 0.0425 mm wide, what is the angular width of the central diffraction peak?
3	At what angle will 510-nm light produce a second-order maximum when falling on a grating whose slits are $1.35\times 10^{-3} cm$ apart?
Past Year	
4	**PSPM 21/22 – Q7(c)** A monochromatic light 600 nm is incident on a diffraction grating with 400 lines per mm. Calculate the a. angle for the first bright order of diffraction. b. maximum number of diffraction pattern that can be formed.
5	**PSPM 20/21 – Q7(b)** A monochromatic light of wavelength 620 nm is incident on a single slit and forms a diffraction pattern on a screen 1.2 m away. The distance of seventh dark fringe from the central maximum is 18.0 mm. Determine the a. Size of the single slit b. Distance of the second bright fringe from the central maximum
6	**PSPM 16/17 – Q6(c)** A beam consists of two monochromatic lights 400 nm and 600 nm, is incident normally on a diffraction grating which has 540 lines mm^{-1}. Calculate the a. Angular separation between the first order diffraction of lights b. Highest order of diffraction that be observed with the 600nm light.
7	**PSPM 15/16 – Q6(c)** White light is incident on a soap film of refractive index 1.33 in air. The reflected light looks bluish because the red light of wavelength 670 nm is absent in the reflection. a. Does the light change phase when it reflects at air-film interface? Explain your answer. b. Does the light change phase when it travels in film and reflects at film-air interface? c. What happen to the wavelength and frequency of light when it travels from air to the film? d. Determine the minimum thickness of the soap film.
Book	
8	Light of wavelength 587.5 nm illuminates a single slit 0.750 mm in width. a. At what distance from the slit should a screen be located if the first minimum in the diffraction pattern is to be 0.850 mm from the centre of the principal maximum? b. What is the width of the central maximum?
9	A source emits 531.62-nm and 531.81-nm light. a. What minimum number of grooves is required for a grating that resolves the two wavelengths in the first-order spectrum? b. Determine the slit spacing for a grating 1.32cm wide that has the required minimum number of grooves.
10	Light that has a wavelength of 668 nm passes through a slit 6.73μm wide and falls on a screen that is 1.85m away. What is the distance on the screen from the centre of the central bright fringe to the third dark fringe on either side?

Exercise Sheet 25: De Broglie

Easy	
1	Calculate the wavelength of a 2kg ball travelling at $0.1ms^{-1}$.
2	What is the wavelength of an electron of energy (a) 10 eV, (b) 100 eV, (c) 1.0 keV?
3	What voltage is needed to produce electron wavelengths of 0.26 nm?
Past Year	
4	**PSPM 21/22 – Q9** De Broglie wavelength of a proton is $1.00 \times 10^{-13}m$. a. Calculate the speed and kinetic energy of the proton. b. Determine the applied electric potential for the proton to accelerate and reach this speed.
5	**PSPM 20/21 – Q9** A particle is moving three times faster than proton. The ratio of the de Broglie's wavelength of the particle to the proton is 1.716 x 10^4. Calculate the mass of particle.
6	**PSPM 19/20 – Q9** A beam of electrons is accelerated through a potential difference of 4500V in a Davisson and Germer experiment. a. Calculate the de Broglie wavelength of the electrons. b. Will the diffraction pattern become larger, remain unchanged or narrower when proton is used instead of electrons? Justify your answer.
7	**PSPM 18/19 – Q9** a. Calculate the speed of a neutron with de Broglie wavelength 9 x 10^{-11}m. b. Calculate the wavelength of an electron that has been accelerated across a potential difference of 100 V.
Book	
8	An electron, starting from rest, accelerates through a potential difference of 418 V. What is the final de Broglie wavelength of the electron, assuming that its final speed is much less than the speed of light?
9	The kinetic energy of a particle is equal to the energy of a photon. The particle moves at 5.0% of the speed of light. Find the ratio of the photon wavelength to the de Broglie wavelength of the particle. *Note: Refer to form 5 physics syllabus.*
10	In an electron diffraction experiment using an accelerating voltage of 54V, an intensity maximum for $\theta = 50^o$. X-ray diffraction indicates that the atomic spacing in the target is $d = 0.218nm$. The electrons have negligible kinetic energy before being accelerated. Find the electron wavelength.

Exercise Sheet 26: Binding Energy & Mass Defect

Easy	
1	Find the binding energy (in MeV) for lithium $^{7}_{3}Li$ (atomic mass = 7.016 003 u).
2	The binding energy of a nucleus is 225.0 MeV. What is the mass defect of the nucleus in atomic mass units?
3	Determine the mass defect (in atomic mass units) for a. Helium $^{3}_{2}He$, which has an atomic mass of 3.016030 u, b. the isotope of hydrogen known as tritium $^{3}_{1}T$, which has an atomic mass of 3.016050 u.
Past Year	
4	**PSPM 21/22 – Q10(a)** Calculate the binding energy of a bromine nucleus ($^{81}_{35}Br$) in Joule. Atomic mass of bromine = 80.916291 u.
5	**PSPM 20/21 – Q10(a)** Calculate the binding energy per nucleon for Thallium, $^{205}_{81}Ti$ in MeV per nucleon. Given atomic mass Tl = 204.974401 u.
6	**PSPM 19/20 – Q10(a)** Calculate the binding energy per nucleon of a sodium nucleus ($^{23}_{11}Na$) in MeV nucleon. The atomic mass of sodium is 22.989769 u.
Book	
7	Show that the nucleus $^{8}_{4}Be$ (mass = 8.005305 u) is unstable and will decay into two α particles. Is $^{12}_{6}C$ stable against decay into three particles? Show why or why not.
8	How much energy is required to remove a. a proton, b. a neutron, from $^{15}_{7}N$ (of mass =15.000109u). Explain the difference in your answers. The mass of $^{14}_{6}C$ and $^{14}_{7}N$ are 14.003242u and 14.003074u respectively.

Exercise Sheet 27: Radioactivity

Easy	
1	In 9.0 days the number of radioactive nuclei decreases to one-eighth the number present initially. What is the half-life (in days) of the material?
2	The $^{32}_{15}P$ isotope of phosphorus has a half-life of 14.28 days. What is its decay constant in units of s^{-1}?
3	The number of radioactive nuclei present at the start of an experiment is 4.6×10^{15}. The number present twenty days later is 8.14×10^{14}. What is the half-life (in days) of the nuclei?
Past Year	
4	**PSPM 21/22 – Q10(b)** A sample consists of 2g of a radioactive element. The molar mass of the element is 67 g. If the half-life of the element is 78 hours, calculate the activity of the sample after 30 hours.
5	**PSPM 20/21 – Q10(b)** Radioactive nuclei have a half-life of 0.99 s. Determine the time taken for 25% of the nuclei to decay away.
6	**PSPM 19/20 – Q10(b)** Calculate the activity of a 5μg ^{24}Na which has a half-life of 14.9 hours.
7	**PSPM 18/19 – Q10(b)** A 2 g sample of radioactive iodine $^{131}_{53}I$ has a half-life of 8 days. a. Calculate the decay constant b. Calculate the initial number of atoms in 2g sample. c. Calculate the activity of the sample after 2 days.
Book	
8	Two radioactive nuclei A and B are present in equal numbers to begin with. Three days later, there are three times as many A nuclei as there are B nuclei. The half-life of species B is 1.50 days. Find the half-life of species A.
9	A 12.0 g sample of carbon from living matter decays at the rate of 184 decays/minute due to the radioactive C-14 in it. What will be the decay rate of this sample in a. 1000 years b. 50,000 years if the half-life of C-14 is 5730years?
10	$^{7}_{4}Be$ decays with a half-life of about 53 d. It is produced in the upper atmosphere, and filters down onto the Earth's surface. If a plant leaf is detected to have 350Bq of $^{7}_{4}Be$, a. how long do we have to wait for the decay rate to drop to 25 per second? b. Estimate the initial mass of on the leaf.

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