IB Physics SL - Study Guide

Science Skills

List the seven fundamental base units and their abbreviations:

	Unit	Abbreviation
Length	Meter	m
Mass	Kilogram	kg
Time	Second	s
Electric Current	Ampere	A
Temperature	Kelvin	K
Amount of Substance	Mole	mol
Luminous Intensity	Candela	cd

Metric Prefixes – List the unit prefixes in their appropriate decimal position

P	T	G	M	k	h	da	d	c	m	μ	n	p	f
10^{15}	10^{12}	10^{9}	10^{6}	10^{3}	10^{2}	10^{1}	10^{-1}	10^{-2}	10^{-3}	10^{-6}	10^{-9}	10^{-12}	10^{-15}

Dimensional Analysis

Convert the following:

20 mi hr^{-1} → m s^{-1}

$$\frac{20\ mi}{1\ hr} \times \frac{1609\ m}{1\ mi} \times \frac{1\ hr}{60\ min} \times \frac{1\ min}{60\ s} = 8.9\frac{m}{s} = 8.9\ m\ s^{-1}$$

0.0007 km^2 → m^2

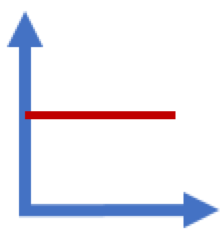
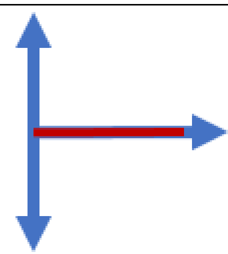
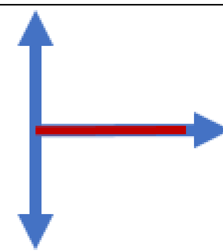
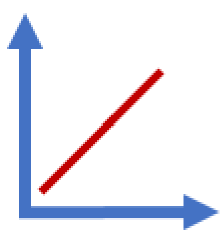
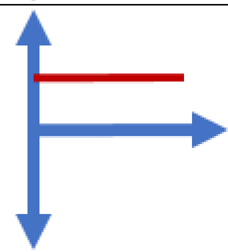
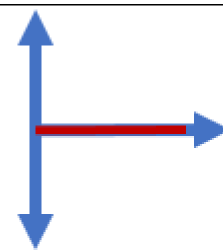
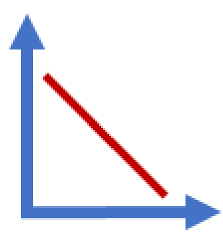
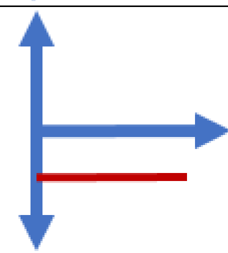
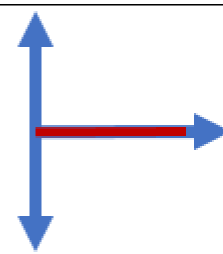
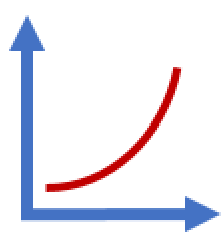
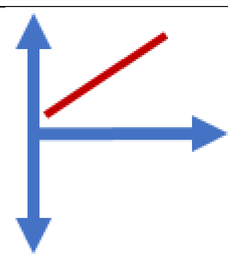
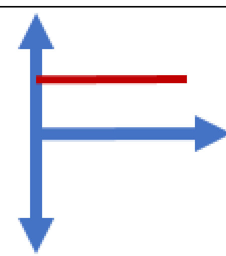
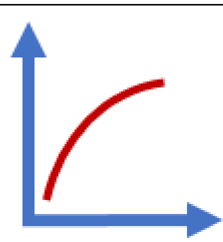
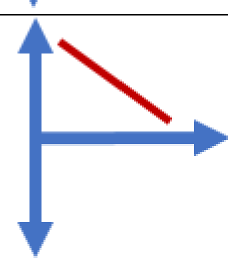
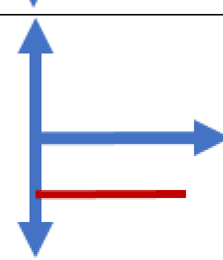
$$0.0007\ km^2 \times \frac{1000\ m}{1\ km} \times \frac{1000\ m}{1\ km} = 700\ m^2 \quad \text{or} \quad 0.0007\ km^2 \times \left(\frac{1000\ m}{1\ km}\right)^2 = 700\ m^2$$

Determine the units for Q:

Q = mc ΔT	m (mass)	kg
$Q = (kg)(J\ kg^{-1}\ K^{-1})(K) = \frac{(kg)(J)(K)}{kg\ K} = J$	c (specific heat)	J kg^{-1} K^{-1}
	ΔT (change in temp)	K

Motion

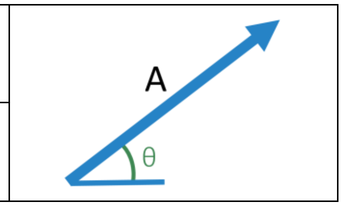
	Scalar	Vector
How far (m)	Distance	Displacement
How fast (m s^{-1})	Speed	Velocity

	Displacement vs Time	Velocity vs Time	Acceleration vs Time
Meaning of the Graph	Slope: Velocity	Slope: Acceleration Area under the Curve: Displacement	Area under the Curve: Velocity
Constant Displacement			
Constant Positive Velocity			
Constant Negative Velocity			
Constant Positive Acceleration (speeding up)			
Constant Negative Acceleration (slowing down)			

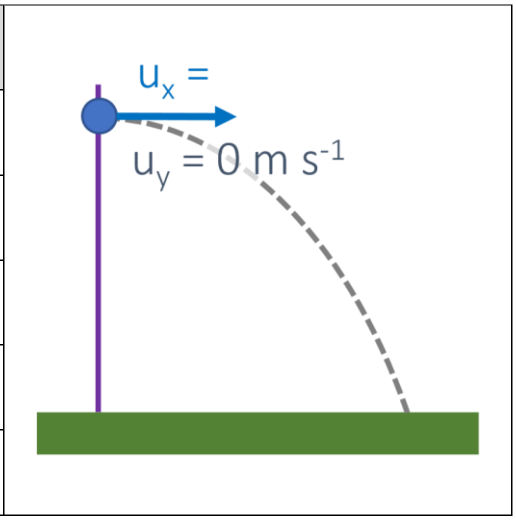
	Variable Symbol	Unit
Displacement	s	m
Initial Velocity	u	m s^{-1}
Final Velocity	v	m s^{-1}
Acceleration	a	m s^{-2}
Time	t	s

Kinematic Equations	s	u	v	a	t
$v = u + at$		✔	✔	✔	✔
$s = ut + \frac{1}{2}at^2$	✔	✔		✔	✔
$v^2 = u^2 + 2as$	✔	✔	✔	✔	
$s = \frac{(v+u)t}{2}$	✔	✔	✔		✔

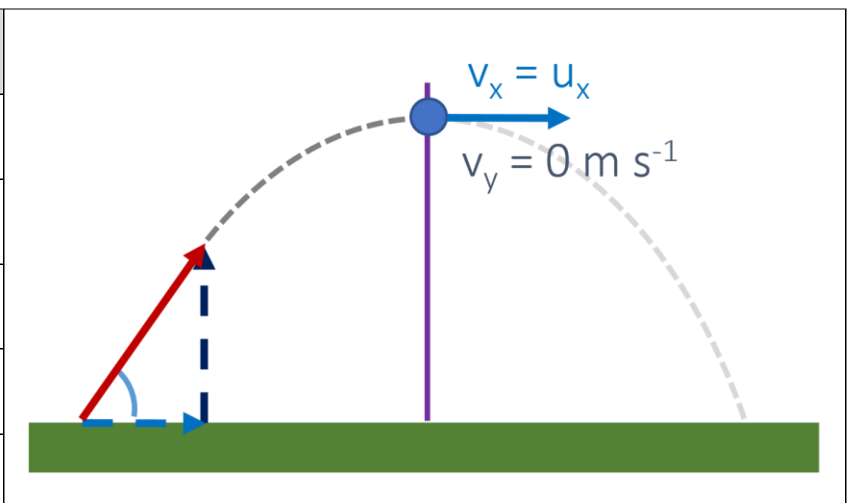
Horizontal Component	$A_H = A\cos\theta$
Vertical Component	$A_V = A\sin\theta$



	Vertical
s	
u	0 m s^{-1}
v	
a	-9.81 m s^{-2}
t	



	Vertical
s	
u	u sinθ
v	0 m s^{-1}
a	-9.81 m s^{-2}
t	



Forces

Type of Force	Variable	Description/Important Properties	Equation
Weight	F_g	Force of gravity on an object with mass	$F_g = mg$
Tension	F_T	Always pulls in the same direction as the rope or chain providing the tension	
Normal Reaction	R	Always perpendicular to a surface	
Friction	F_f	Always opposes the motion of an object	$F_f = \mu R$
Air Resistance	F_{air}	Increases with surface area and velocity	

If an object has a net force of zero its motion is either:

Not moving (velocity = 0 m s^{-1})	or	Moving at a constant velocity

Newton's Laws

Newton's First Law	A object at rest remains at rest and an object in motion remains in motion until and unless an external force acts upon it (Unbalanced force).
Newton's Second Law	The rate of change of momentum of an object is proportional to the resultant force acting on the body and is in the same direction. ($F = ma$)
Newton's Third Law	All forces occur in pairs. Every action has an equal and opposite reaction

Data Booklet Equations:

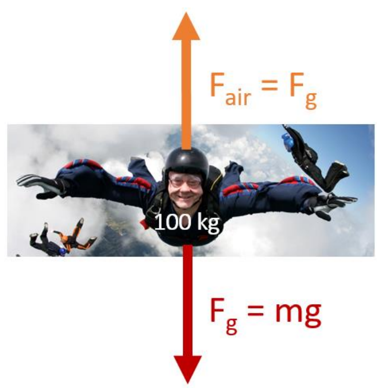
$$F = ma$$

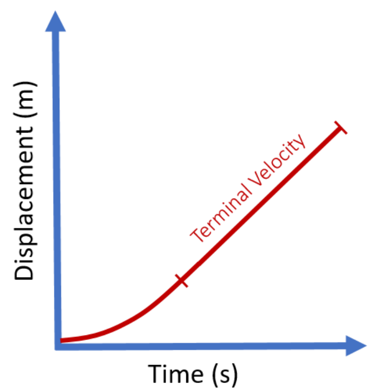
$$F_f \leq \mu_s R$$

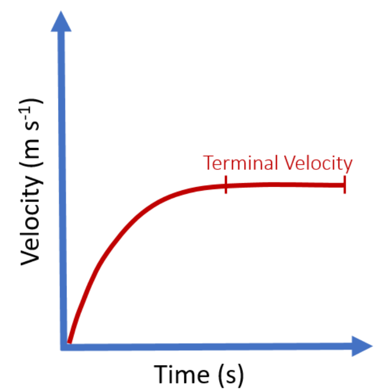
$$F_f = \mu_d R$$

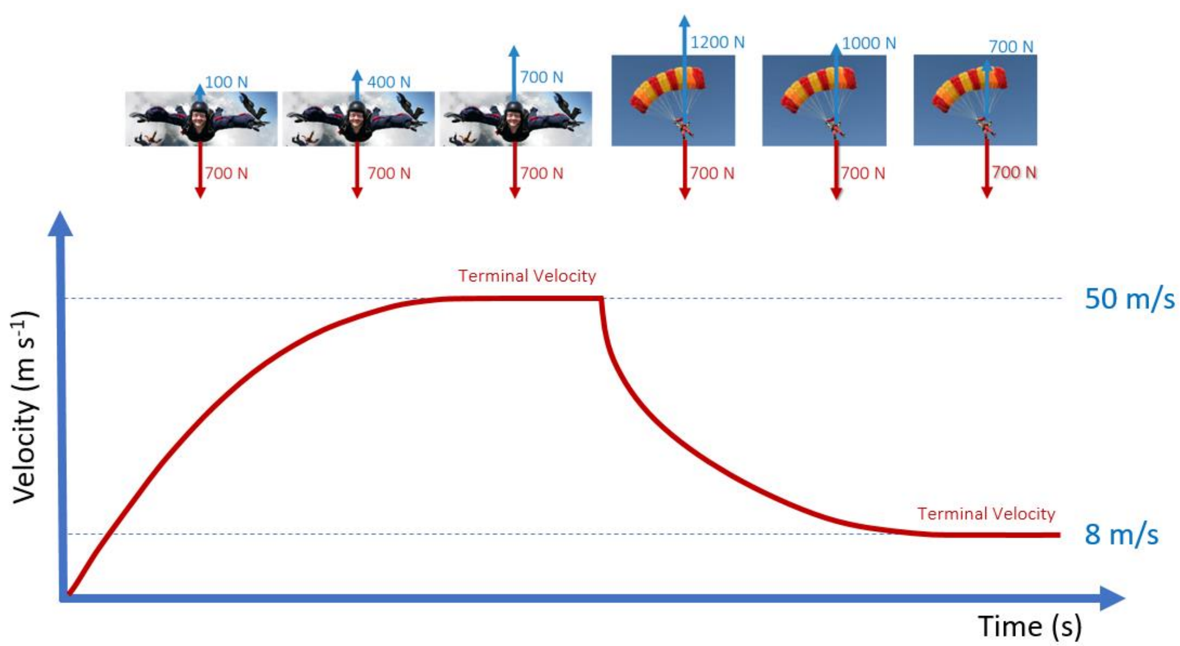
	Variable Symbol	Unit
Force	F	N
Mass	m	kg
Acceleration	a	$m\ s^{-1}$
Normal Reaction Force	R	N
Coefficient of Kinetic Friction	μ_d	--
Coefficient of Static Friction	μ_s	--

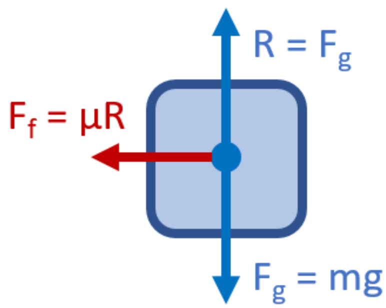
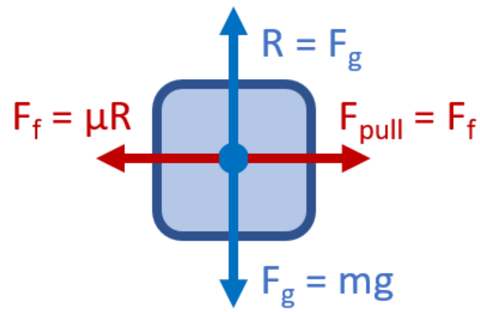
Terminal Velocity	The maximum velocity a falling body can achieve. This occurs when the force of air resistance is equal and opposite to the weight and $F_{net} = 0$ N.

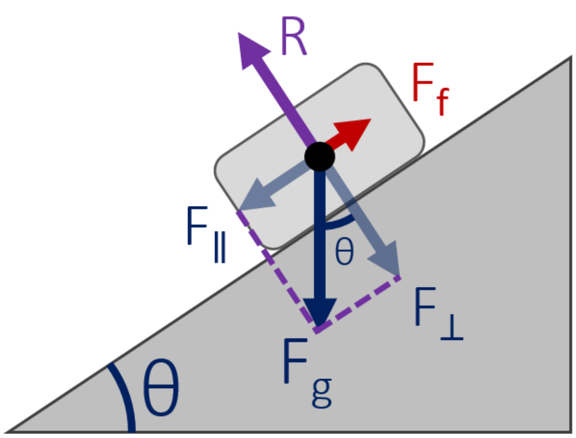








Sliding to a Stop	Constant Velocity	
		
$F_{net} = F_f$	$F_{net} = 0$ N	$F_{pull} = F_f$



$F_{\perp}$	$F_g \cos\theta$
$F_{\parallel}$	$F_g \sin\theta$

Forces on a Ramp

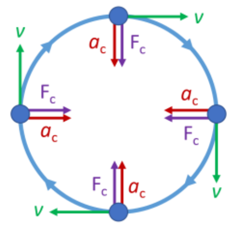
Equilibrium	
R	$F_{\perp}$
F_f	$F_{\parallel}$
F_{net}	0 N
a	0 m s^{-1}

Accelerating	
R	$F_{\perp}$
F_f	μR
F_{net}	$F_{\parallel} - F_f$
a	F_{net} / m

Circular Motion

	Variable Symbol	Unit
Distance	d	m
Angular Distance	θ	rad
Angular Velocity	ω	rad s^{-1}
Linear Velocity	v	m s^{-1}
Centripetal Acceleration	*a*	m s^{-2}
Centripetal Force	F_c	N

Draw in vectors for v, a_c, and F_c →



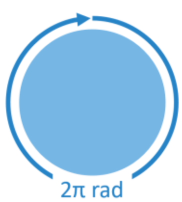
Data Booklet Equations:

$$v = \omega r$$

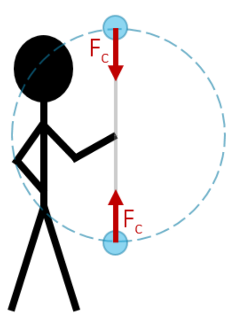
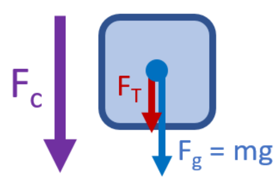
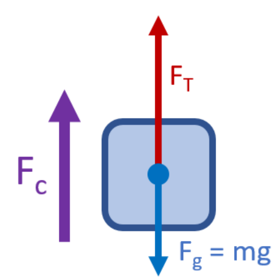
$$a = \frac{v^2}{r} = \frac{4\pi^2 r}{T^2}$$

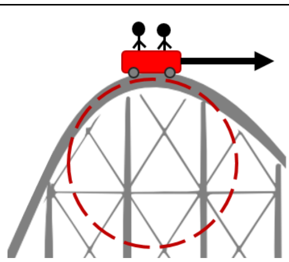
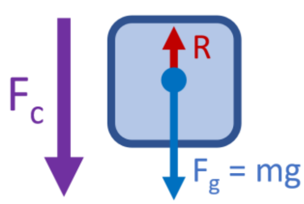
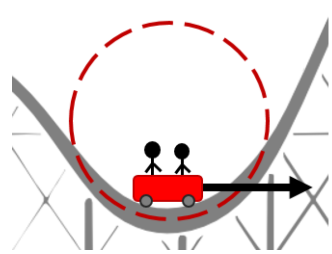
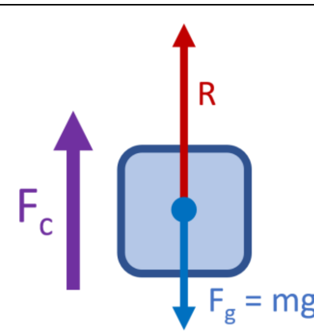
$$F = \frac{mv^2}{r} = m\omega^2 r$$

Defining Circular Motion

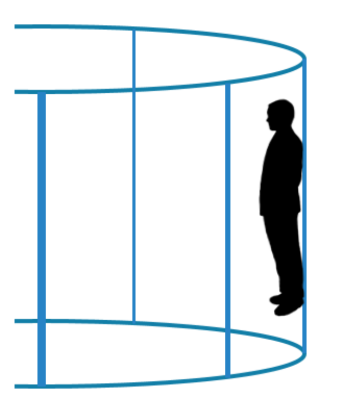
	Period	T	s	Angular Velocity	ω	rad s^{-1}
	Time per revolution			$\omega = \frac{2\pi}{T}$		

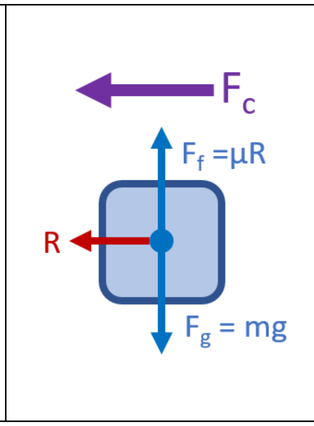
Vertical Circular Motion

	Top:	Bottom:
		
	$F_{net} = F_c = F_T + F_g$	$F_{net} = F_c = F_T - F_g$

Top:		Bottom:	
			
$F_{net} = F_c = F_g - R$		$F_{net} = F_c = R - F_g$	

Circular Motion with Friction and Angles

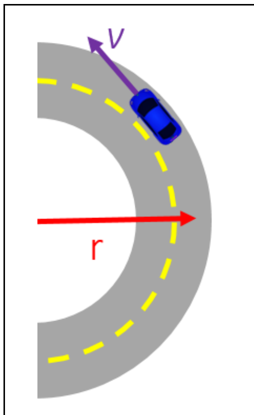


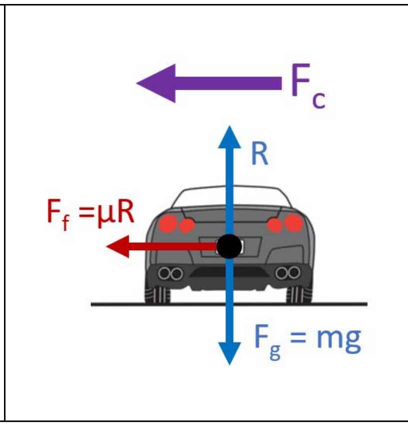


Relationships between variables:

$$F_f = F_g$$

$$F_c = R$$

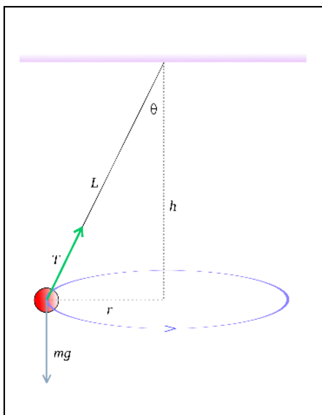


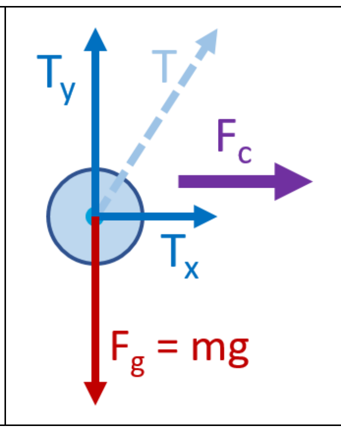


Relationships between variables:

$$R = F_g$$

$$F_c = F_f$$





Relationships between variables:

$$T_y = F_g$$

$$F_c = T_x$$

Energy

	Variable Symbol	Unit
Work	W	Joules [J]
Power	P	Watts [W]
Kinetic Energy	E_k	J
Elastic Potential Energy	E_p	J
Gravitational Potential Energy	ΔE_p	J
Spring Constant	k	N m^{-1}
Spring Stretch	Δx	m

Data Booklet Equations:

$$W = Fs\cos\theta$$

$$E_k = \frac{1}{2}mv^2$$

$$E_p = \frac{1}{2}k\Delta x^2$$

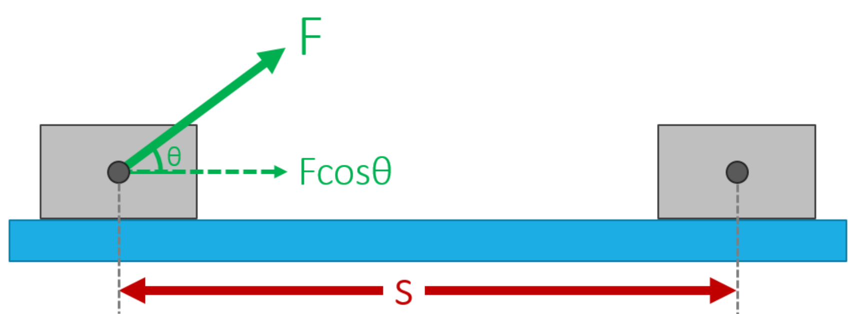
$$\Delta E_p = mg\Delta h$$

$$\text{power} = Fv$$

Calculating Work

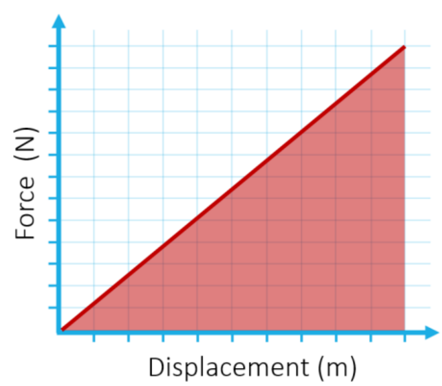
Constant force at an angle:

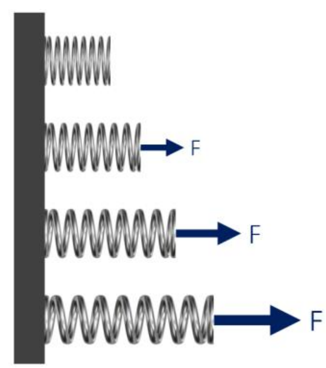
$$W = Fs\cos\theta$$



Varying Force:

Area under the curve





Examples of no work being done for an object in motion:

- Pushing something that doesn't move (no displacement, no work)
- Waiter carrying a tray horizontally (force is vertical, motion is horizontal)
- Orbiting object (velocity is tangent to path, force is toward the center)

Calculating Power

In terms of work and time:	*In terms of force and velocity:*
$$Power = \frac{Work}{Time}$$	$$Power = Force \times Velocity = Fv$$

Units

	Standard Unit	From Equation	Fundamental SI Units
Work	J	N m	kg m^2 s^{-2}
Power	W	J s^{-1}	kg m^2 s^{-3}

Types of Energy

Kinetic Energy	Elastic Potential Energy	Gravitational Potential Energy
$\frac{1}{2}mv^2$	$\frac{1}{2}k\Delta x^2$	$mg\Delta h$

Conservation of Energy

Total Energy Before = Total Energy After

Work-Energy Theorem

Work → Energy	Energy → Work
$Fs = \frac{1}{2}mv^2$	$\frac{1}{2}mv^2 = Fs$

Momentum

	Variable Symbol	Unit
Momentum	p	kg m s^{-1}
Mass	m	kg
Velocity	v	m s^{-1}
Time	t	s
Kinetic Energy	E_K	J
Impulse	Impulse	N s or kg m s^{-1}

Data Booklet Equations:

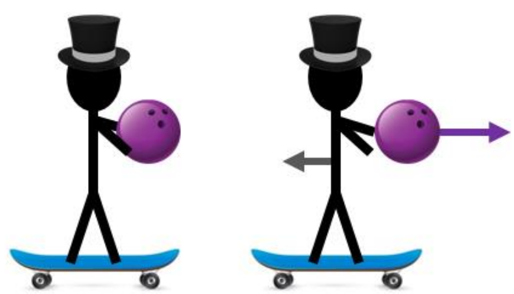
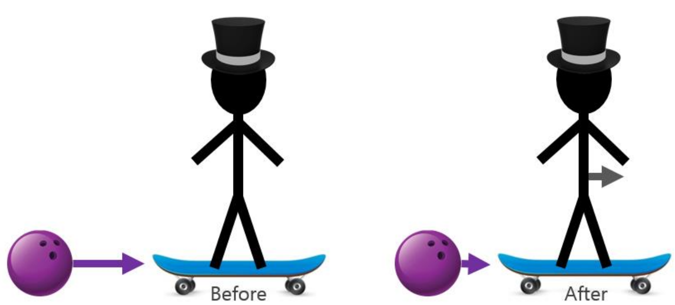
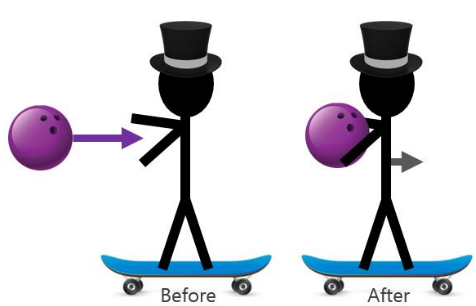
$$p = mv$$

$$F = \frac{\Delta p}{\Delta t}$$

$$E_K = \frac{p^2}{2m}$$

$$\text{Impulse} = F\Delta t = \Delta p$$

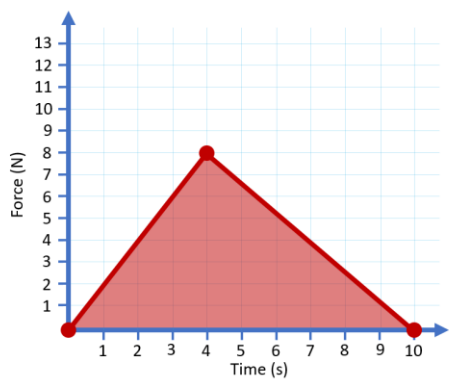
Conservation of Energy Problems

	"Explosion" $p_{AB} = p_A + p_B$
	"Hit and Bounce" $p_A + p_B = p_A + p_B$
	"Hit and Stick" $p_A + p_B = p_{AB}$

Types of Collisions

Elastic	Kinetic Energy is conserved (perfect hit and bounce) *Typically just found in particle collisions
Inelastic	Kinetic Energy is not conserved

Calculating Impulse

Constant force: Force × Time $F\Delta t$	
Varying Force: Area under a Force vs Time Graph	

Impulse-Momentum Equation

$$F\Delta t = \Delta p = m\Delta v = mv - mu$$

Collision Safety

Explain (using impulse, force, and time) how to decrease the force acting on an object undergoing a collision:

Impulse is the same overall regardless of the impact style because the object has a set mass and impact velocity. The force can be decreased by increasing the time of the impact.

Impulse = FΔt   or   Impulse = FΔt

Waves – Sound

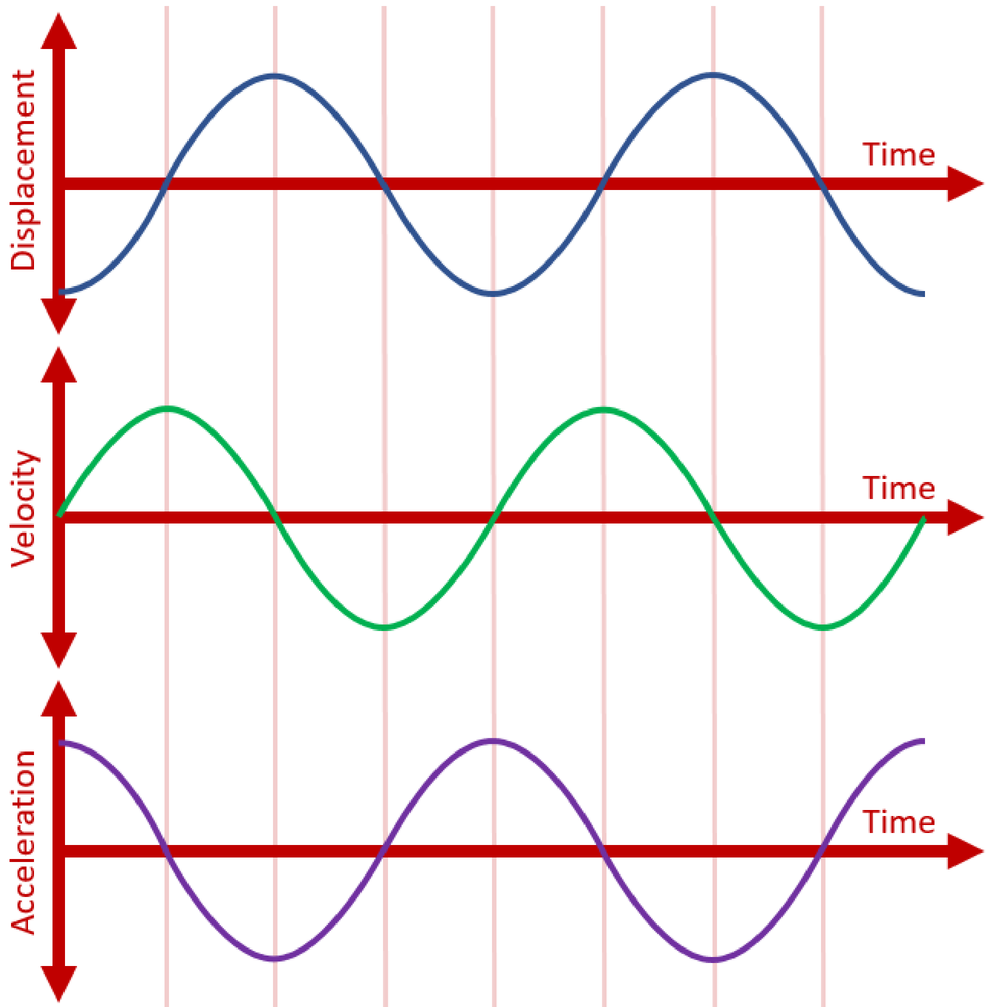
	Variable Symbol	Unit
Period	T	s
Frequency	f	Hz
Wavelength	λ	m
Amplitude	A	m
Wave Speed	v	m s^{-1}

Data Booklet Equations:

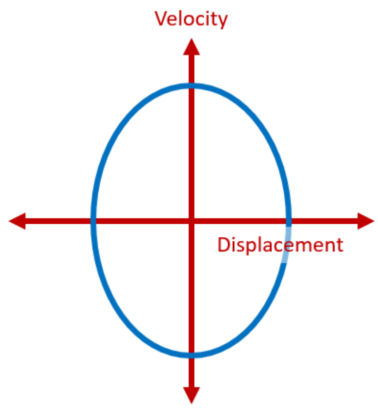
$$T = \frac{1}{f}$$

$$c = f\lambda$$

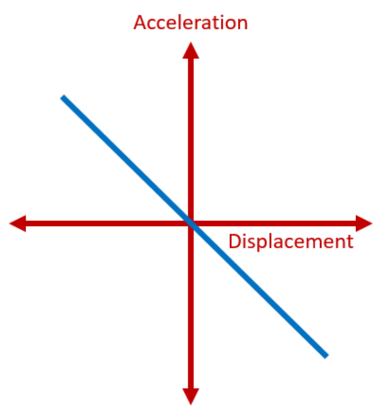
Simple Harmonic Motion Graphs



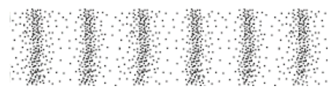
Velocity vs Displacement



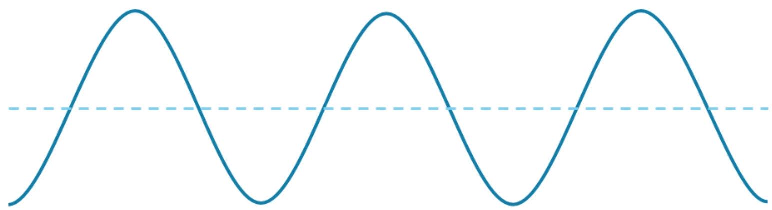
Accel. vs Displacement



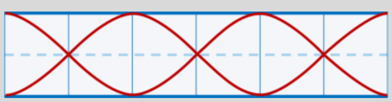
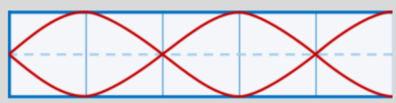
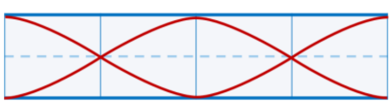
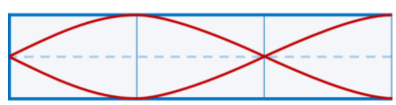
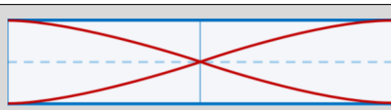
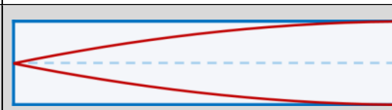
Types of Waves

Types of Waves	Picture	Definition	Examples
Transverse		Particles move **perpendicular** to the motion of the wave	• Light • Ripples in a Pond • Earthquakes
Longitudinal		Particles move **parallel** to the motion of the wave	• Sound • Earthquakes

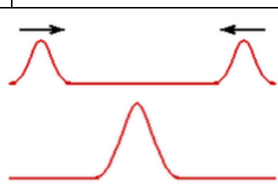
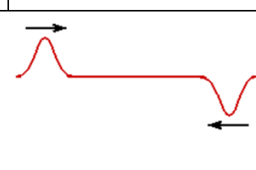
Parts of a Wave

<u>Label the Wave:</u> • Amplitude • Wavelength • Crest • Trough	

Harmonics

	Open Pipe		Closed Pipe		String	
End Conditions	Antinode	Antinode	Node	Antinode	Node	Node
3rd Harmonic	 $L = \frac{3}{2}\lambda$		 $L = \frac{5}{4}\lambda$		 $L = \frac{3}{2}\lambda$	
2nd Harmonic	 $L = 1\lambda$		 $L = \frac{3}{4}\lambda$		 $L = 1\lambda$	
1st Harmonic (Fundamental)	 $L = \frac{1}{2}\lambda$		 $L = \frac{1}{4}\lambda$		 $L = \frac{1}{2}\lambda$	

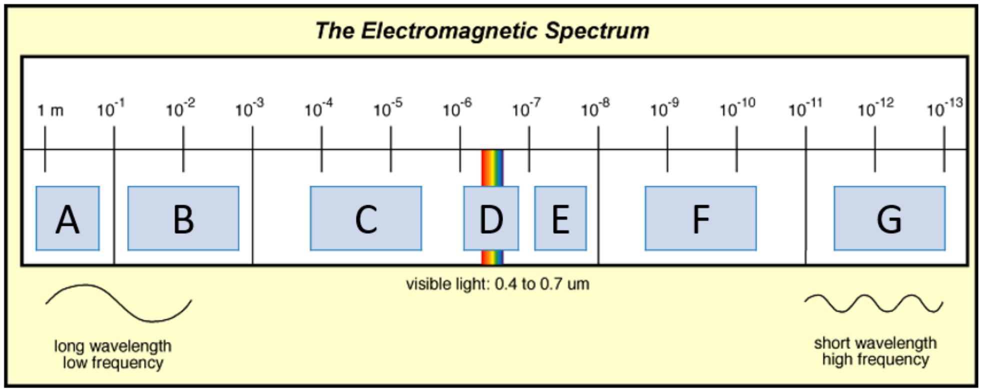
Interference

Constructive	Path Difference = $n\lambda$	*Destructive*	Path Difference = $(n + ½)\lambda$
			

Waves – Light

Electromagnetic Spectrum

A	Radiowaves
B	Microwaves
C	Infrared
D	Visible Light
E	Ultraviolet
F	X-Rays
G	Gamma Waves



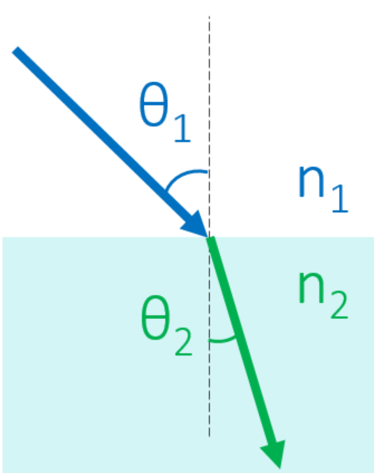
Index of Refraction

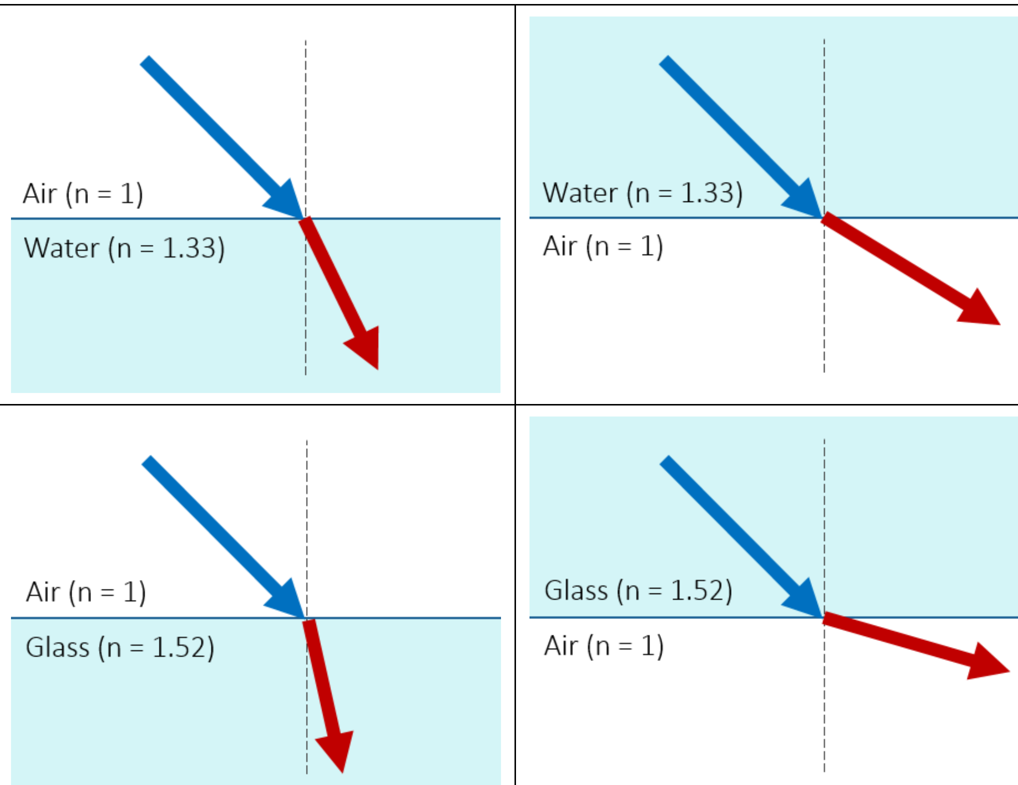
Medium	Wave Speed (v)	Index of Refraction (n)
Vacuum	3.00×10^8 m s^{-1}	1.0000
Air	2.999×10^8 m s^{-1}	1.0003
Water	2.256×10^8 m s^{-1}	1.33
Glass	1.974×10^8 m s^{-1}	1.52

$$\frac{n_1}{n_2} = \frac{v_2}{v_1}$$

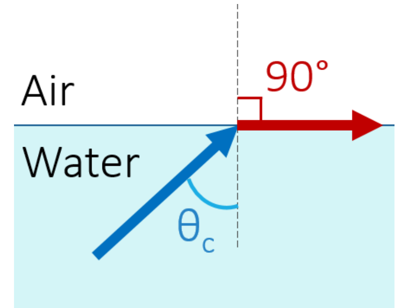
Refraction

$$\frac{n_1}{n_2} = \frac{sin\theta_2}{sin\theta_1}$$

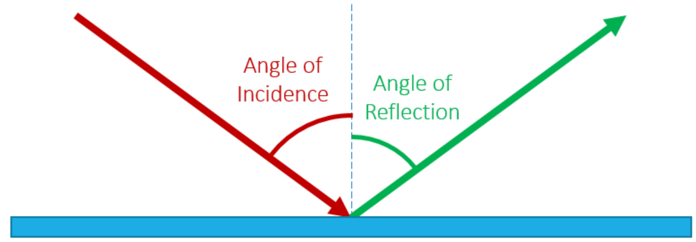




Critical Angle

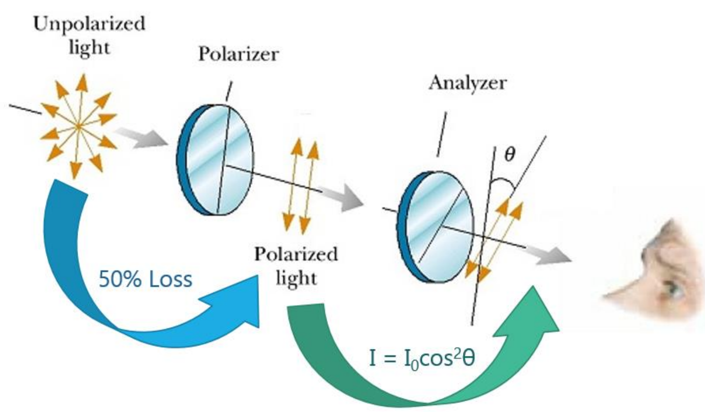
When $\theta_1 = \theta_c$ $\theta_2 = 90°$	$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$	

Reflection

Law of Reflection	
Angle of Incidence = Angle of Reflection	

Polarized Light

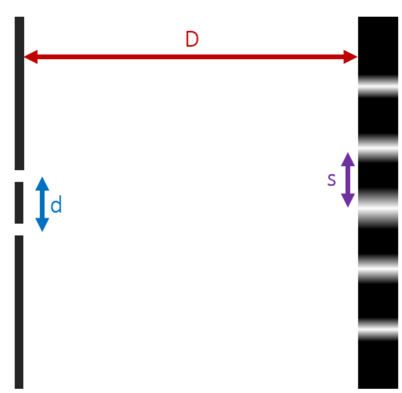
$I = I_0 \cos^2\theta$	
I	Intensity Observed
I_0	Original Intensity
θ	Difference in Angle



Double Slit Experiment

$s = \frac{\lambda D}{d}$	
s	Distance between fringes
λ	Wavelength
D	Distance to Screen
d	Distance between slits

Label this diagram:



Electricity

Charge

Symbol	q	Unit	Coulombs [C]
Charge of 1 Electron		1.6×10^{-19} C	
# of Electrons per Coulomb		6.25×10^{18} e^-	

Current

Symbol	I	Unit	Amperes [A]
Unit in terms of Coulombs		$A = \frac{C}{s}$	

Drift Speed

	Variable Symbol	Unit
Current	I	A
# of Electrons per m^3	n	---
Cross Sectional Area	A	M^2
Drift Speed	v	$m\ s^{-1}$
Charge	q	C

Data Booklet Equation:

$$I = nAvq$$

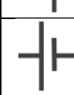
Cross Sectional Area:

$$A = \pi r^2$$

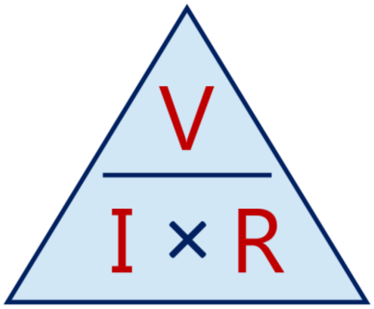
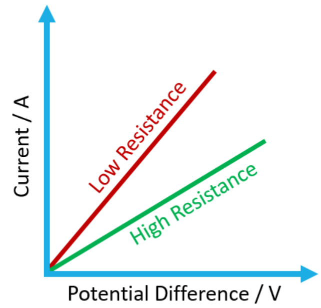
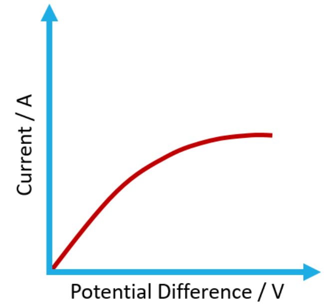
Electrical Properties

Property	What is it?	Symbol	Unit
Voltage	Potential Difference	V	Volts [V]
Current	The rate at which charges move through a wire	I	Amperes [A]
Resistance	How hard it is for a current to flow through a conductor	R	Ohms [Ω]

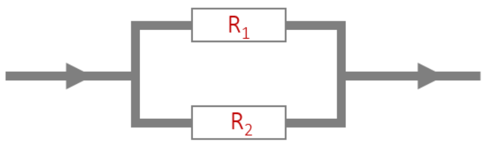
Kirchhoff's Laws

$\Sigma I = 0$ (junction)				$\Sigma V = 0$ (loop)			
The total current coming into a junction must equal the total current leaving the same junction				The sum of the voltages (potential differences) provided must equal the voltages dissipated across components			
				Across resistors	Always Negative		
Entering Junction	→	●	Positive	Negative to Positive	→		Positive
Exiting Junction	●	→	Negative	Positive to Negative	→		Negative

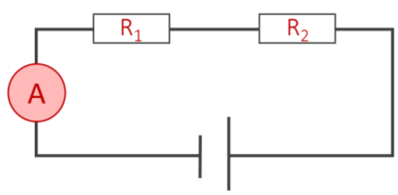
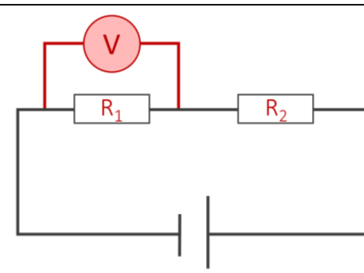
Ohm's Law

	$V = I \times R$	Ohmic Resistor 	Non-Ohmic Resistor 
	$I = \frac{V}{R}$		
	$R = \frac{V}{I}$		

Equivalent Resistance

	Drawing with R_1 and R_2	Equation
Series		$R_{total} = R_1 + R_2 + \cdots$
Parallel		$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$

Measuring Circuits

	Ammeter	Voltmeter
Ideal Resistance	R = 0 Ω	R = ∞ Ω
How is it connected to the component being measured?	Ammeters must be connected in **series**	Voltmeters must be connected in **parallel**
Drawing of meter measuring R_1		

Resistivity

	Variable Symbol	Unit
Resistivity	ρ	Ω m
Resistance	R	Ω
Cross Sectional Area	A	m^2
Length	L	m

Data Booklet Equation:

$$\rho = \frac{RA}{L}$$

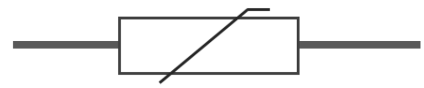
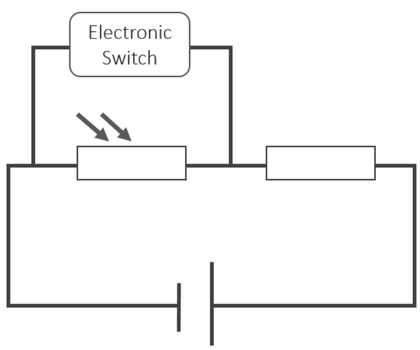
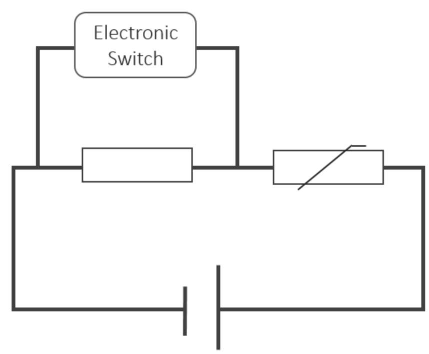
Cross Sectional Area:

$$A = \pi r^2$$

Power

In terms of V and I	In terms of I and R	In terms of V and R
$P = V \times I$	$P = I^2R$	$P = \frac{V^2}{R}$

Voltage Dividers

	Light-Dependent Resistor		Thermistor	
Symbol				
Relationship	Light	Increases	Heat	Increases
	Resistance	Decreases	Resistance	Decreases
Circuit	Switch turns on in the dark: 		Switch turns on in a fire: 	

Batteries

Primary Cells	Secondary Cells
Cannot be recharged	*Can be recharged by passing a current through the battery in the opposite direction as it would normally travel*

	Variable Symbol	Unit
Electromotive Force (e.m.f)	ε	V
Current	I	A
Circuit Resistance	R	Ω
Internal Resistance	r	Ω

Data Booklet Equation:

$$\varepsilon = I(R + r)$$

Force Fields

Forces between objects

Coulomb's Law

	Variable Symbol	Unit
Electrostatic Force	F	N
Object 1 Charge	q_1	C
Object 2 Charge	q_2	C
Separation Distance	r	M
Coulomb Constant	k	$N\ m^2\ C^{-2}$
Permittivity of Free Space	ε_0	$C^2\ N^{-1}\ m^{-2}$

Data Booklet Equations:

$$F = k\frac{q_1 q_2}{r^2}$$

$$= \frac{1}{4\pi\varepsilon_0}$$

$k = 8.99 \times 10^9\ N\ m^2\ C^{-2}$
$\varepsilon_0 = 8.85 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$

Universal Law of Gravitation

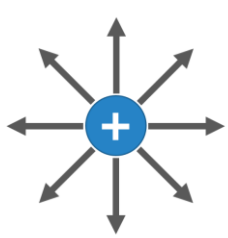
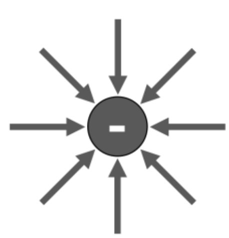
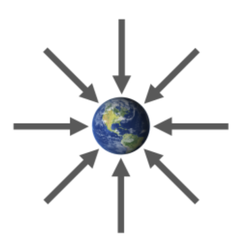
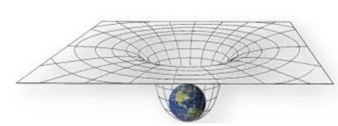
	Variable Symbol	Unit
Gravitational Force	F	N
Object 1 Mass	M	kg
Object 2 Mass	m	kg
Separation Distance	r	m
Gravitational Constant	G	$N\ m^2\ kg^{-2}$

Data Booklet Equation:

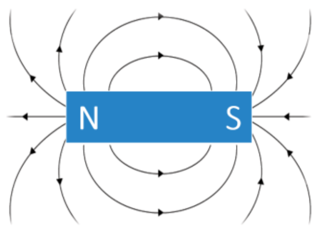
$$F = G\frac{Mm}{r^2}$$

$G = 6.67\ N\ m^2\ kg^{-2}$

Force Fields

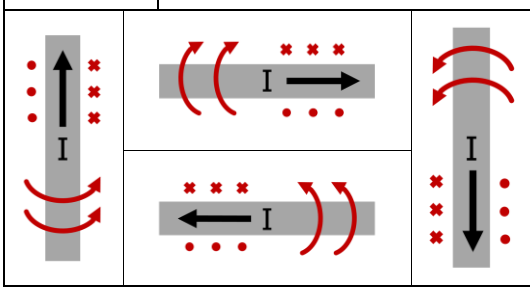
Electric Field			Gravitational Field		
					
Symbol	E	*Data Booklet Equation:* $E = \frac{F}{q}$	Symbol	g	*Data Booklet Equation:* $g = \frac{F}{m}$ $g = G\frac{M}{r^2}$
Units	$F\ C^{-1}$		Units	$F\ kg^{-1}$	

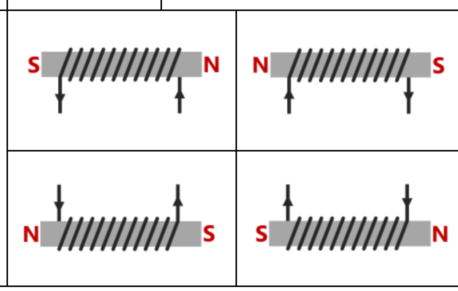
Magnetic Fields

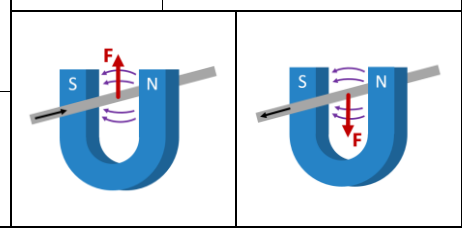


Right Hand Rule:

Right Hand Rule #1		Right Hand Rule #2		Right Hand Rule #3	
Magnetic field around a current carrying wire		Pole orientation for a coil of wire (electromagnet, solenoid, etc.)		Electromagnetic force direction on a wire or moving particle	
Thumb	Current	Thumb	North Pole	Thumb	Current
Fingers	Magnetic Field	Fingers	Current	Fingers	Magnetic Field
				Palm	Force







Electromagnetic Force

	Variable Symbol	Unit
Magnetic Force	F	N
Magnetic Field Strength	B	T
Current	I	A
Wire Length	L	m
Angle to Field	θ	°
Particle Charge	q	C
Particle Velocity	v	$m\ s^{-1}$

Data Booklet Equations:

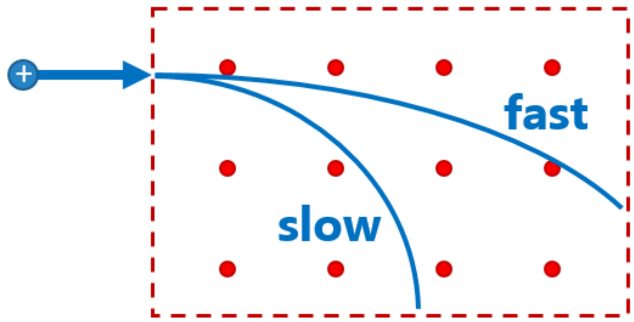
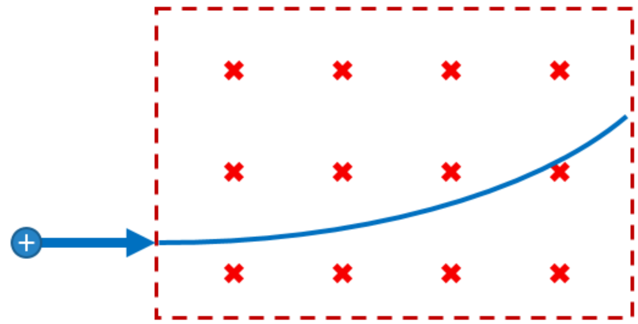
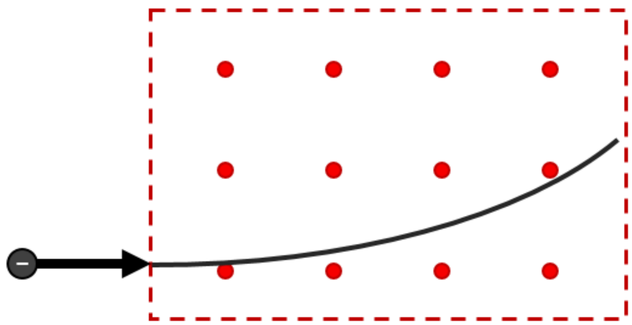
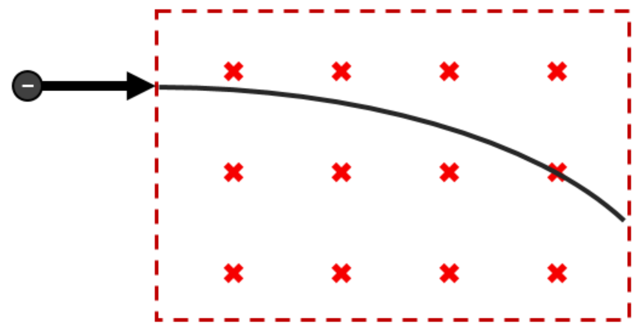
Wire:

$$F = BIL\sin\theta$$

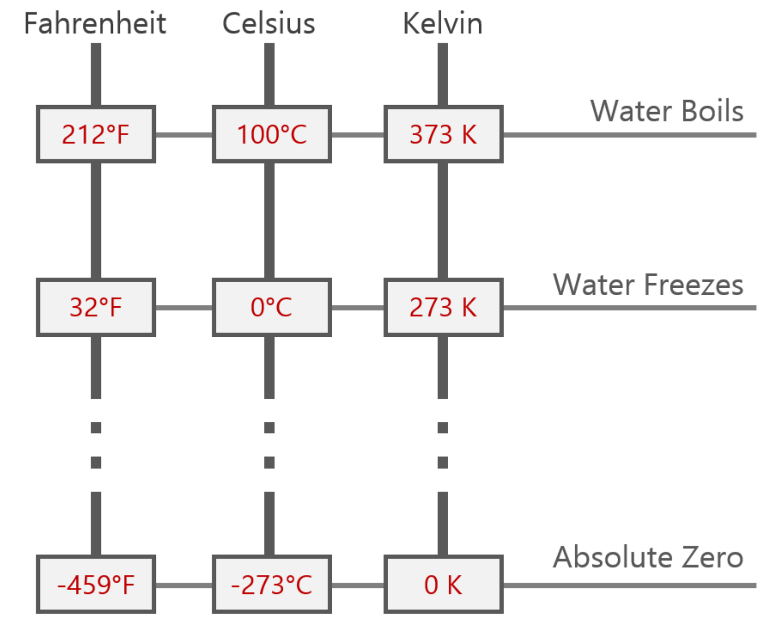
Particle:

$$F = qvB\sin\theta$$

Charged Particles Moving through a Magnetic Field

	Magnetic Field | Out of Screen	Magnetic Field | Into Screen
Positive Particle		
Negative Particle		

Thermal Physics



Data Booklet Equation:

$$\text{Temperature (K)} = \text{Temperature (°C)} + 273$$

Conditions for Absolute Zero:

Molecules stop moving. This is the coldest possible temperature.

Absolute Zero = 0 K = -273 K

Specific Heat Capacity and Specific Latent Heat

	Variable Symbol	Unit
Heat Energy	Q	J
Mass	m	kg
Specific Heat Capacity	c	J kg^{-1} K^{-1}
Change in Temperature	ΔT	K
Specific Latent Heat	L	J kg^{-1}

Data Booklet Equations:

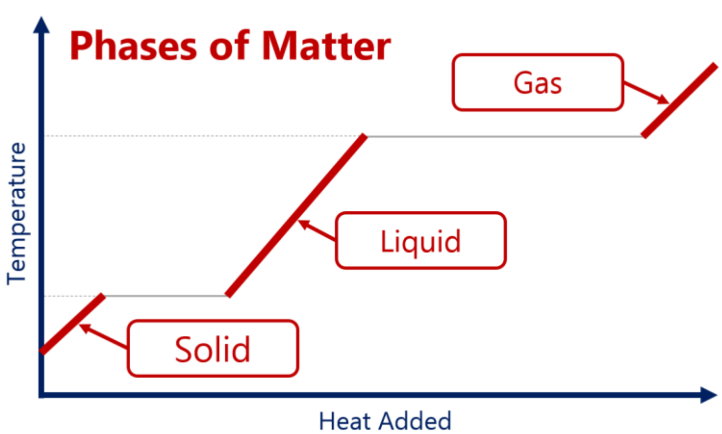
$$Q = mc\Delta T$$

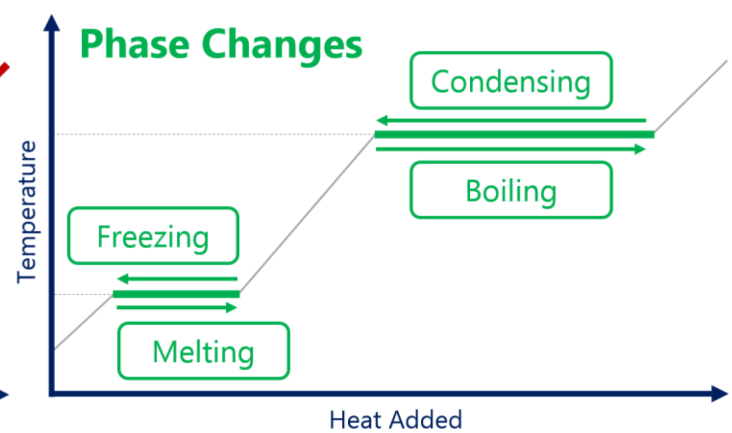
$$Q = mL$$

E_K	Kinetic Energy → Temperature

E_P	Potential Energy → Phase Change

Heating Curves





Pressure

	Variable Symbol	Unit	
Force	F	N	
Area	A	m^3	
Pressure	p	$N\ m^{-3}$	Pa

Data Booklet Equation:

$$p = \frac{F}{A}$$

Kinetic Theory and Temperature

	Variable Symbol	Unit
Average Kinetic Energy	$\bar{E}_k$	J
Absolute Temperature	T	K
Boltzmann's Constant	k_b	$J\ K^{-1}$

Data Booklet Equation:

$$\bar{E}_K = \frac{3}{2}k_B T = \frac{3}{2}\frac{R}{N_A}T$$

$k_B = 1.38 \times 10^{-23}\ J\ K^{-1}$

Avogadro's Number	N_A	6.02×10^{23}

Ideal Gas Law

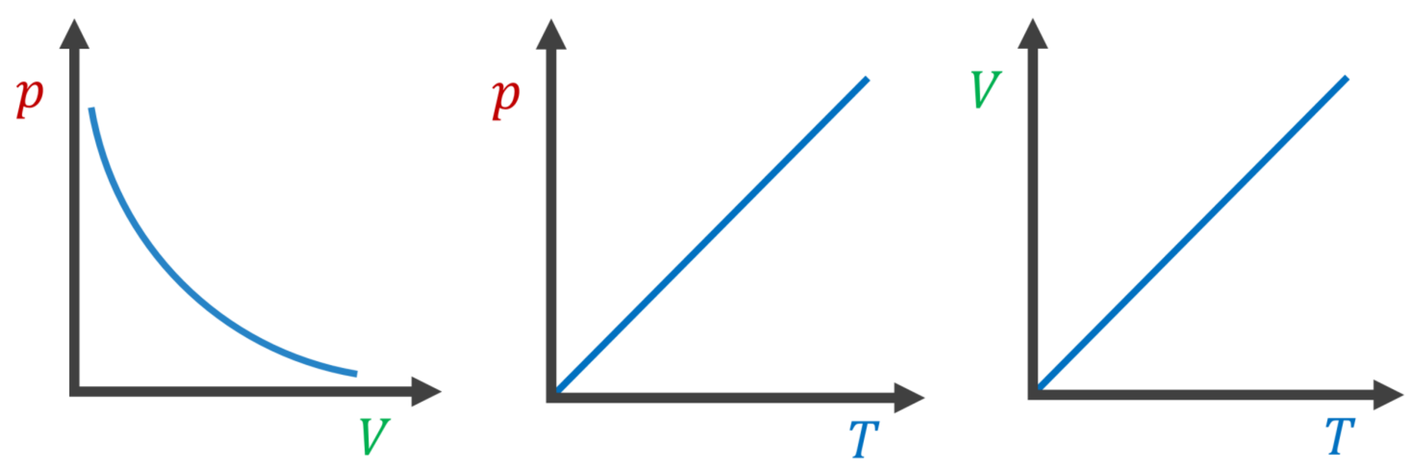
	Variable Symbol	Unit
Pressure	p	Pa
Volume	V	m^{-3}
Number of Molecules	n	mol
Gas Constant	R	$J\ K^{-1}\ mol^{-1}$
Temperature	T	K

Data Booklet Equations:

$pV = nRT$ | $R = 8.31\ J\ K^{-1}\ mol^{-1}$

Conditions for Ideal Gases:

Ideal Gas Relationships

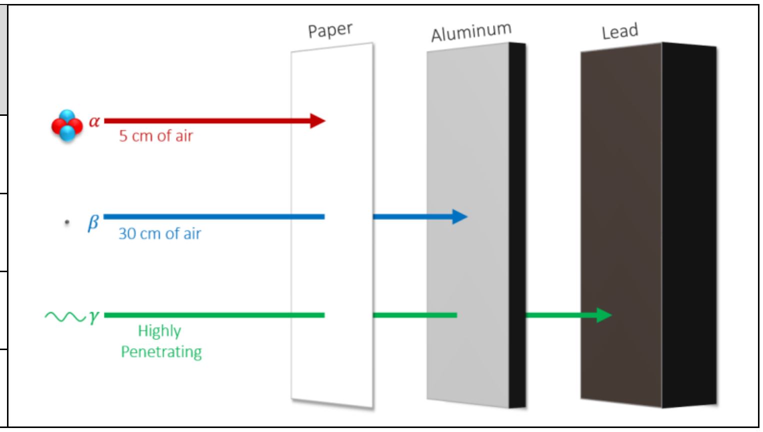


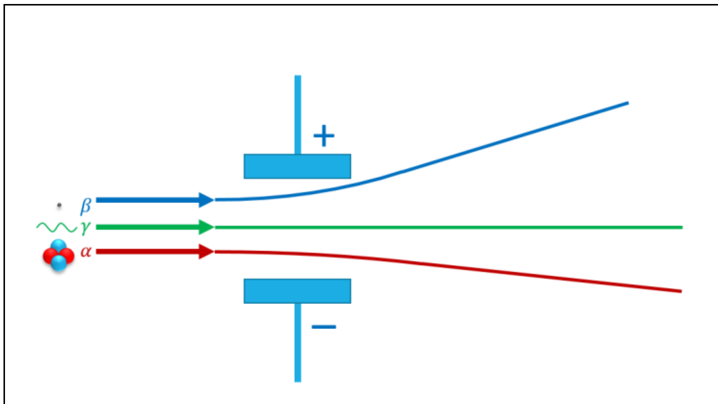
Atomic Physics

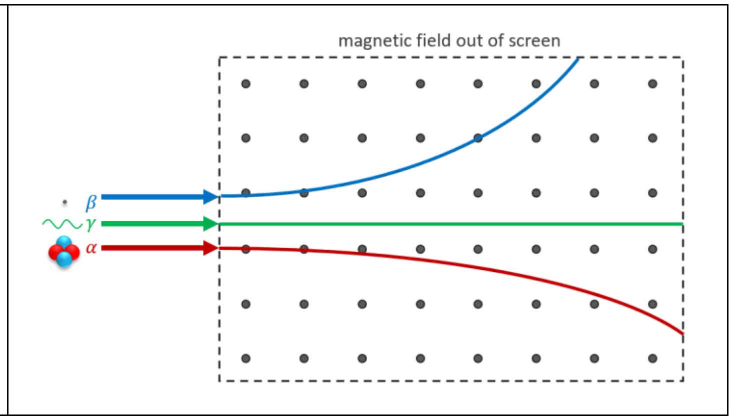
Types of Decay

Alpha	Beta-Negative	Beta-Positive
$^{A}_{Z}X \rightarrow\, ^{A-4}_{Z-2}X +\, ^{4}_{2}He$	$^{A}_{Z}X \rightarrow\, _{Z+1}^{A}X +\, _{-1}^{0}e + \bar{\nu}_e$	$^{A}_{Z}X \rightarrow\, _{Z-1}^{A}X +\, _{+1}^{0}e + \nu_e$
Parent Nuclide; Daughter Nuclide; Alpha Particle	Parent Nuclide; Daughter Nuclide; Electron; Anti-neutrino	Parent Nuclide; Daughter Nuclide; Positron; Neutrino

Property	Alpha (α)	Beta (β+ or β-)	Gamma (γ)
Relative Charge	+2	+1 or -1	0
Relative Mass	4	0.0005	0
Typical Speed	10^7 m s^{-1}	2.5×10^8 m s^{-1}	3.0×10^8 m s^{-1}
Ionizing Effect	Strong	Weak	Very Weak

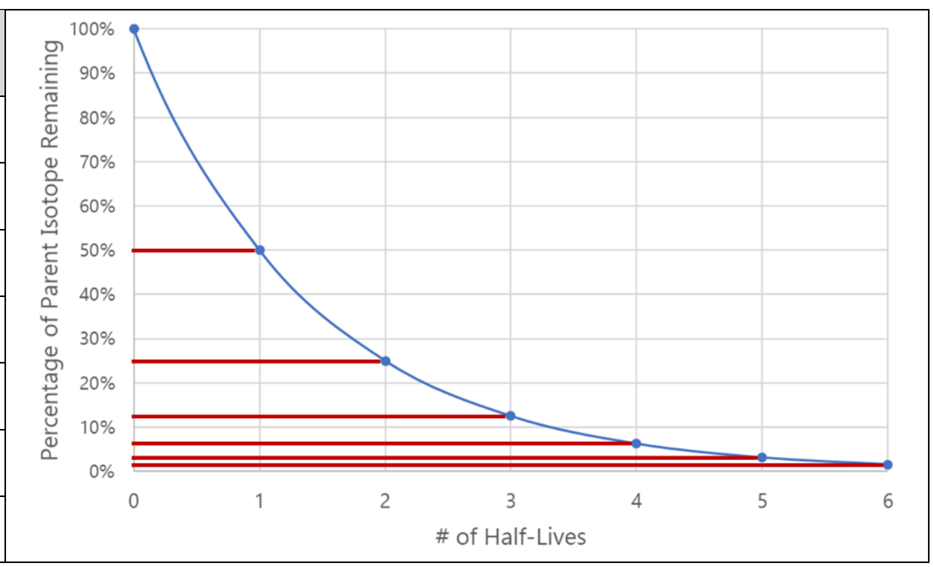






Half Life

# of Half-Lives	Fraction Remaining	Percentage Remaining
0	1	100%
1	1/2	50%
2	1/4	25%
3	1/8	12.5%
4	1/16	6.25%
5	1/32	3.125%
6	1/64	1.5625%



Mass-Energy Equivalence

	Variable Symbol	Unit
Energy	E	J
Mass	m	kg
Speed of Light	c	m s^{-1}

Data Booklet Equation:

$$E = mc^2$$

$$c = 3.00 \times 10^8 \; m \; s^{-1}$$

Unified Atomic Mass Unit	u	1.661×10^{-27} kg	1.000000 u	931.5 MeV c^{-2}

Electron Rest Mass	m_e	9.110×10^{-31} kg	0.000549 u	0.511 MeV c^{-2}
Proton Rest Mass	m_p	1.673×10^{-27} kg	1.007276 u	938 MeV c^{-2}
Neutron Rest Mass	m_n	1.675×10^{-27} kg	1.008665 u	940 MeV c^{-2}

Converting between Joules and Electron-Volts

$\{Energy\ in\ eV\} = \dfrac{\{Energy\ in\ J\}}{1.60 \times 10^{-19}}$	$\{Energy\ in\ J\} = \{Energy\ in\ eV\} \times 1.60 \times 10^{-19}$

Process for Calculating Binding Energy

1. Add up the "before and after" masses
2. Find the mass defect by taking the difference
3. Convert atomic mass units (u) into MeV c^{-2} by using the conversion factor 1 u = 931.5 MeV c^{-2}
4. The c^{-2} cancels out when converting to energy using E = mc^2 so this is your binding energy

	Describe	Examples	Challenges
Fission	Lighter elements are created by splitting heavier elements	Nuclear Power Nuclear Weapons	Proper amounts of fissionable elements required to maintain chain reaction
Fusion	Heavier elements are created by combining lighter elements	The Sun/Stars	Requires high heat and high pressure

Fundamental Particles

The following two tables are provided in the IB Physics Data Booklet

Charge	Quarks			Baryon Number
$\frac{2}{3}$	u	c	t	$\frac{1}{3}$
$-\frac{1}{3}$	d	s	b	$\frac{1}{3}$
All quarks have a strangeness number of 0 except the strange quark that has a strangeness number of –1				

Charge	Leptons		
-1	e	μ	τ
0	ν_e	ν_μ	ν_τ
All leptons have a lepton number of 1 and antileptons have a lepton number of –1			

Quarks			
Symbol	Name	Charge	Baryon #
u	Up	$+\frac{2}{3}$	$\frac{1}{3}$
d	Down	$-\frac{1}{3}$	$\frac{1}{3}$
c	Charm	$+\frac{2}{3}$	$\frac{1}{3}$
s	Strange	$-\frac{1}{3}$	$\frac{1}{3}$
t	Top	$+\frac{2}{3}$	$\frac{1}{3}$
b	Bottom	$-\frac{1}{3}$	$\frac{1}{3}$

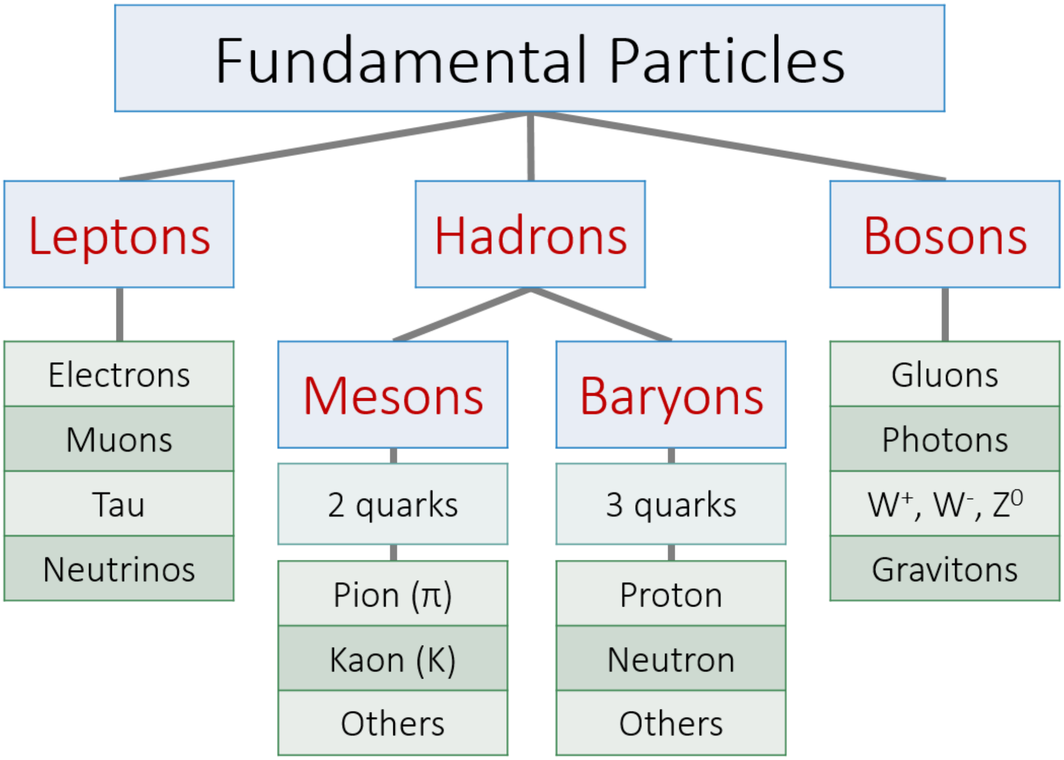
Leptons			
Symbol	Name	Charge	Lepton #
e	Electron	-1	1
μ	Muon	-1	1
τ	Tau	-1	1
ν_e	Electron Neutrino	0	1
ν_μ	Muon Neutrino	0	1
ν_τ	Tau Neutrino	0	1

Anti-Quarks			
Symbol	Name	Charge	Baryon #
$\bar{u}$	Antiup	$-\frac{2}{3}$	$-\frac{1}{3}$
$\bar{d}$	Antidown	$+\frac{1}{3}$	$-\frac{1}{3}$
$\bar{c}$	Anticharm	$-\frac{2}{3}$	$-\frac{1}{3}$
$\bar{s}$	Antistrange	$+\frac{1}{3}$	$-\frac{1}{3}$
$\bar{t}$	Antitop	$-\frac{2}{3}$	$-\frac{1}{3}$
$\bar{b}$	Antibottom	$+\frac{1}{3}$	$-\frac{1}{3}$

Anti-Leptons			
Symbol	Name	Charge	Lepton #
$\bar{e}$	Antielectron (positron)	$+1$	-1
$\bar{\mu}$	Antimuon	$+1$	-1
$\bar{\tau}$	Antitau	$+1$	-1
$\bar{\nu}_e$	Electron Antineutrino	0	-1
$\bar{\nu}_\mu$	Muon Antineutrino	0	-1
$\bar{\nu}_\tau$	Tau Antineutrino	0	-1

Explain the phenomenon of **Quark Confinement**:

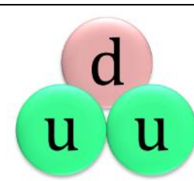
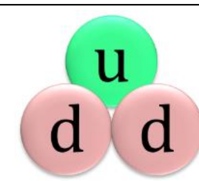
Quarks have never been observed on their own. The amount of energy required to overcome the strong nuclear force holding the quarks together gets converted into mass and forms a new quark pair.



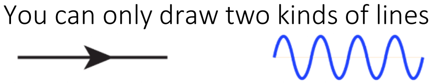
Fundamental Forces

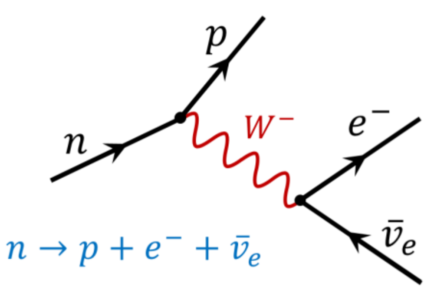
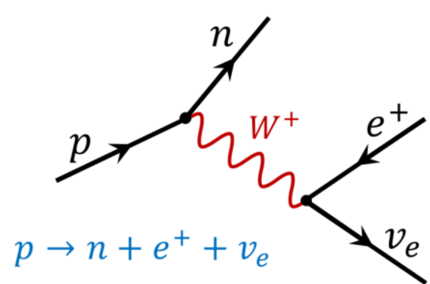
	Strength	Distance
Gravitational	Weakest	Long Range
Weak	Weak	Short Range
Electromagnetic	Strong	Very Long Range
Strong	Strongest	Very Short Range

Particle Configurations

Proton		Neutron	
			
Total Charge	+1	Total Charge	0

Feynman Diagrams

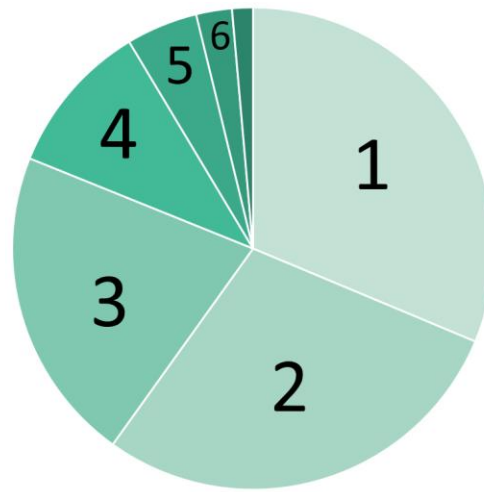
You can only draw two kinds of lines 	You can *only* connect these lines if you have two lines with arrows meeting a single wiggly line	The x-axis represents time and is read from left to right. Everything left of the vertex is the "before" condition.

Beta-Negative Decay	Beta-Positive Decay
	

Energy Production

Global Energy Usage

Rank	Energy Source	%
1	Oil	32%
2	Coal	28%
3	Natural Gas	22%
4	Biomass	10%
5	Nuclear	5%
6	Hydropower	2.5%

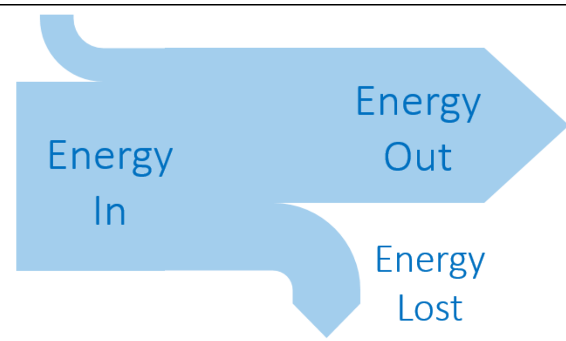


Efficiency

$$Efficiency = \frac{useful\ work\ out}{total\ work\ in} = \frac{useful\ power\ out}{total\ power\ in}$$

Sankey Diagram Rules:

Width of the arrow proportional to the amount of energy



Energy Density

	Definition	Units
Specific Energy	Energy transferred per unit mass	$J\ kg^{-1}$
Energy Density	Energy transferred per unit volume	$J\ m^{-3}$

Primary and Secondary Sources

Primary Energy Sources	Secondary Energy Sources
Energy sources found in the natural environment (fossil fuels, solar, wind, nuclear, hydro, etc.)	Useful transformations of the primary sources (electricity, pumped storage for hydro, etc.)

Fossil Fuels

Number of years left in global reserves	
Coal	~100-150 years
Oil	~50 years
Natural Gas	~50 years

Describe the process of **Fracking**:
1. Drill hole into shale rock 2. Inject fracking fluid at high pressure to create cracks 3. Extract newly released natural gas 4. Seal fracking fluid in the hole

Nuclear Power

	% of U-235
Uranium Ore	0.7%
Fuel-Grade	3.5%
Weapons-Grade	90%

Why is the concentration of U-235 important? Only U-235 can undergo a fission chain reaction
What is done with the nuclear waste? Stored on-site in spent fuel pools and/or concrete dry cask storage

Moderator	Control Rods
Slows down neutrons to be absorbed by U-235 Made from Water or Graphite (carbon)	Absorbs neutrons to limit number of chain reactions Made from Boron

Renewable Energy

	Variable Symbol	Unit
Power	P	W
Cross-Sectional Area	A	m^2
Air Density	ρ	$kg\ m^{-3}$
Air Speed	v	$m\ s^{-1}$

Data Booklet Equations:

$$\text{Power} = \frac{1}{2}A\rho v^3$$

$$A = \pi r^2$$

Photovoltaic Cells	Solar Concentrator	Solar Heating Panel
Converts solar energy directly into electricity. Useful in solar panels on top of building or solar farms connected to the energy grid	Mirrors focus sunlight onto a central tower. The high thermal energy is converted to steam and runs turbines to produce electricity	Sun's radiation is absorbed by black pipes that transfer thermal energy to the water flowing through them. Replaces hot water heater.

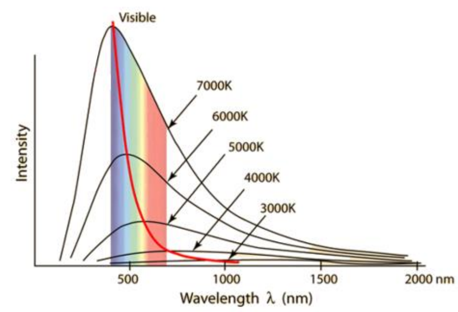
	Biomass	Coal	Geothermal	Hydropower	Natural Gas	Nuclear	Petroleum	Solar	Wind
Renewable	✓		✓	✓				✓	✓
Produces CO_2	✓	✓			✓		✓		

Thermal Energy Transfer

Conduction	Convection	Radiation
Energy is transferred through molecular collisions	Energy circulates through the expansion and rising of hot fluids	Energy is transferred through electromagnetic radiation. Can travel through a vacuum

	Emissivity
Sun	~1
Earth	~0.6
Black-Body	1

Black Body Radiation
An idealized object that absorbs **all** the electromagnetic radiation the falls on it



Power Emissivity	Variable Symbol	Unit
Power	P	W
Emissivity	e	---
Surface Area	A	m^2
Temperature	T	K
Max Wavelength	λ_{max}	m

Data Booklet Equations:

$$P = e\sigma A T^4$$

$$\lambda_{max} = \frac{2.90 \times 10^{-3}}{T}$$

$$\sigma = 5.67 \times 10^{-8}\ \mathrm{W\ m^{-2}\ K^{-4}}$$

Solar Radiation and Climate Change

Intensity	Variable Symbol	Unit
Intensity	I	$W\ m^{-2}$
Power	P	W
Area	A	m^2

Data Booklet Equations:

$$I = \frac{\text{power}}{A}$$

$$A_{sphere} = 4\pi r^2$$

Greenhouse Gases
Water Vapor (H_2O)
Carbon Dioxide (CO_2)
Methane (CH_4)

Positive Feedback Loop	Negative Feedback Loop
Melting ice (decreases albedo)	Cloud formation (increases albedo)
Melting permafrost (releases methane)	Increased photosynthesis (uses CO_2)
Rising ocean temp releases methane	Climate Change leads to renewables

Astrophysics

The Scale of Astrophysics

Unit Conversion	Definition
1 light year (ly) = 9.46 × 10^{15} m	The distance the light travels in an earth year
1 parsec (pc) = 3.26 ly	The average distance between the earth and the sun
1 astronomical unit (AU) = 1.50 × 10^{11} m	The distance at which the mean radius of the earth's orbit subtends an angle of 1 arc second

Stellar Quantities

Brightness	Luminosity
Star intensity to an observer on earth Units: W m^{-2}	How much total power a star emits Units: W

	Variable Symbol	Unit
Distance	d	pc
Parallax Angle	p	sec
Brightness	b	W m^{-2}
Luminosity	L	W
Max Wavelength	λ_{max}	m
Temperature	T	K
Surface Area	A	m^2

Data Booklet Equations:

$$d\ (\text{parsec}) = \frac{1}{p\ (\text{arc} - \text{second})}$$

$$b = \frac{L}{4\pi d^2}$$

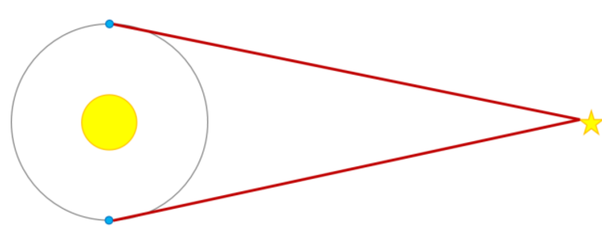
$$\lambda_{\text{max}} T = 2.9 \times 10^{-3}\ \text{m K}$$

$$L = \sigma A T^4$$

$$\sigma = 5.67 \times 10^{-8}\ \text{W m}^{-2}\ \text{K}^{-4}$$

Describe the process of Stellar Parallax:

Observe how far a star moves relative to distant stars six months apart so that earth has its maximum displacement and an angle can be measured



Atomic Spectra

	Variable Symbol	Unit
Energy	E	J or eV
Planck's Constant	h	J s
Frequency	*f*	Hz
Speed of Light	c	m s^{-1}
Wavelength	λ	m

Data Booklet Equations:

$$E = hf$$

$$\lambda = \frac{hc}{E}$$

$$h = 6.63 \times 10^{-34} \text{ J s}$$

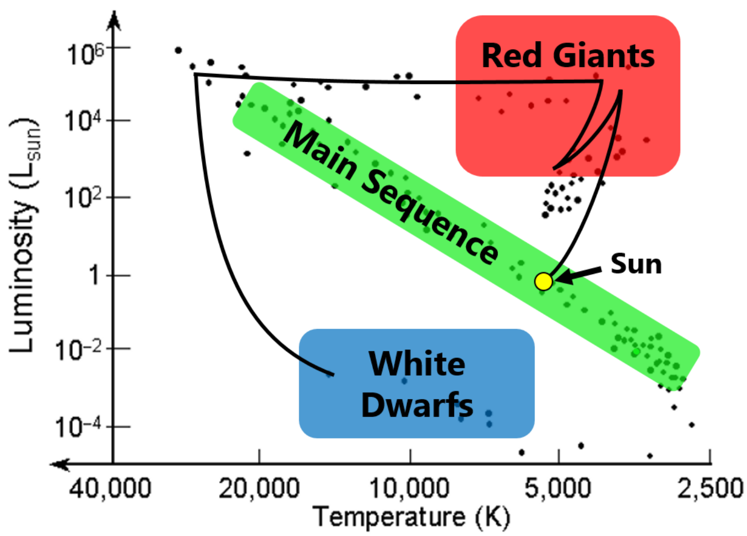
$$c = 3.00 \times 10^{8} \text{ m s}^{-1}$$

hc	1.99×10^{-25} J m	1.24×10^{-6} eV m

H-R Diagrams and Life Cycle of a Star

Label the Following:

- ☐ Main Sequence
- ☐ White Dwarfs
- ☐ Red Giants
- ☐ The Sun
- ☐ Line representing the life cycle of our sun



Chandrasekhar Limit	Oppenheimer-Volkhoff Limit
The maximum mass of a core that can become a white dwarf is 1.4 times the mass of the sun (1.4 $M_\odot$)	The maximum mass of a core that can become a neutron star is 3 times the mass of the sun (3 $M_\odot$)

Sun Like Stars (< 1.5 $M_\odot$)	Huge Stars (1.5 – 3 $M_\odot$)	Giant Stars (> 3 $M_\odot$)
⬇	⬇	⬇
White Dwarf	Neutron Star	Black Hole

The Expanding Universe

Standard Candles	Evidence for Expanding Universe
Objects of known luminosity that can be used with the apparent brightness to measure distance from earth Cephid Variables and Type Ia Supernovas	Hubble discovered that the farther away stars and galaxies are, the more their light is redshifted. This means, more distant objects are traveling faster than nearer objects.

	Variable Symbol	Unit
Redshift	z	---
Change in Wavelength	Δλ	m
Original Wavelength	λ_0	m
Relative Velocity of Source	v	$m\ s^{-1}$
Speed of Light	c	$m\ s^{-1}$
Current Scale Factor	R	---
Scale Factor when Emitted	R_0	---
Hubble's Constant	H_0	$km\ s^{-1}\ Mpc^{-1}$

Data Booklet Equations:

$$z = \frac{\Delta\lambda}{\lambda_0} \approx \frac{v}{c}$$

$$z = \frac{R}{R_0} - 1$$

$$v = H_0 d$$

$$c = 3.00 \times 10^8 \text{ m s}^{-1}$$

$$H_0 \approx 70\ km\ s^{-1}\ Mpc^{-1}$$

The Big Bang

	Peak Wavelength	Temperature
Cosmic Microwave Background Radiation	$\sim 0.001\ m\ (1\ mm)$	$\sim 2.9\ K$

Describe why the CMB is evidence of the Big Bang:

The CMB is the heat signature from the early universe. As the universe has expanded to its current size, the wavelength stretched out to the current value seen in the CMB. This radiation is fairly uniform and it can be observed in every direction.