

Specially prepared for the use of all Services  
and Civilian technical personnel, students, etc.

No. 21

# MANUAL OF SCIENCE

HEAT · LIGHT · SOUND  
DYNAMICS · STATICS  
MECHANICS · HYDRAULICS  
ELECTRICITY · MAGNETISM  
ETC. ETC.

FORMULÆ · DATA · TABLES  
CHARTS · EXAMPLES · ETC. ETC.

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PROPERTIES OF THE ELEMENTS

Name	Atomic Weight	Specific Gravity	Symbol	Melting Point °C	Boiling Point °C	Specific Heat
Aluminium	26.97	2.71	Al	660	2201	.212
Antimony	121.75	6.68	Sb	630	1640	.047
Argon	39.94	1.39	A	-189	-184	
Arsenic	74.92	5.72	As	814		.082
Barium	137.35	3.75	Ba	704	1138	.069
Beryllium	9.02	1.82	Be	1282	1502	
Bismuth	209.1	9.81	Bi	269	1561	.029
Boron	10.82	2.51	B	2250	3542	.306
Bromine	79.92	3.11	Br	-7	59	.181
Cadmium	112.41	8.64	Cd	321	767	.051
Cæsium	132.92	1.87	Cs	29	671	.049
Calcium	40.09	1.54	Ca	852	1174	.153
Carbon	12.01	3.47	C	3512	3934	.212
Cerium	140.13	6.92	Ce	815	1402	.046
Chlorine	35.96	2.48	Cl	-103	-34	.227
Chromium	52.02	7.11	Cr	1831	2261	.105
Cobalt	58.94	8.61	Co	1492	3468	.102
Copper	63.57	8.93	Cu	1084	2357	.091
Dysprosium	162.45		Dy			
Erbium	167.21	4.72	Er			
Europium	152.01		Eu			
Fluorine	19	1.12	F	-224	-108	
Gadolinium	156.9	5.91	Gd			
Gallium	69.71	5.95	Ga	30	2312	.079
Germanium	72.61	5.47	Ge	958		.073
Gold	197.2	19.32	Au	1063	2361	.032
Hafnium	178.61		Hf	2228		
Helium	4.01	.12	He	-272	-269	
Holmium	163.49		Ho			
Hydrogen	1.01	.082	H	-257	-249	
Inolium	114.75	7.3	In	156	1420	.056
Iodine	126.92	4.95	I	114	185	.054
Iridium	193.11	22.41	Ir	2455	2552	.031
Iron	55.84	7.86	Fe	1528	3234	.105
Krypton	83.71	2.16	Kr	-157	-153	
Lanthanum	138.91	6.11	La	812		.044
Lead	207.21	11.37	Pb	327	1755	.031
Lithium	6.94	.54	Li	186	1432	.961
Lutecium	175.1		Lu			
Magnesium	24.32	1.74	Mg	659	1104	.244
Manganese	54.93	7.39	Mn	1242	1902	.122
Mercury	200.61	13.55	Hg	-39	357	.033
Molybdenum	95.96	10.11	Mo	2621	3563	.065
Neodymium	144.26	6.96	Nd	840		
Neon	20.18		Ne	-249	-246	
Nickel	58.68	8.91	Ni	1455	3076	.107
Niobium	92.91	8.49	Nb	1951	-196	
Niton	222		Nt			
Nitrogen	14.01	.78	N	-210		
Osmium	190.21	22.48	Os	2710		.032
Oxygen	16	1.27	O	-219	-183	
Palladium	106.7	11.4	Pd	1553		.054
Phosphorus	31.02	2.12	P	44	279	.199
Platinum	195.22	21.51	Pt	1773	4310	.031
Potassium	39.09	.862	K	64	759	.104
Praseodymium	140.91	6.47	Pr	941		
Protactinium	231.25		Pa			
Radium	226.05	5	Ra	961		
Radon	222		Rn			
Rhenium	186.32		Re	3166		
Rhodium	102.92	12.43	Rh	1966	2502	.057
Rubidium	85.49	1.53	Rb	39	696	
Ruthenium	101.71	12.31	Ru	1902	2521	.062
Samarium	150.44		Sm	1372		
Scandium	45.11		Sc	1202		
Selenium	78.97	4.7	Se	220	685	.089
Silicon	28.07	2.31	Si	1415	2391	.146
Silver	107.88	10.49	Ag	960	2152	.056
Sodium	22.99	.97	Na	98	877	.283
Strontium	87.64	2.54	Sr	772	1364	
Sulphur	32.07	1.99	S	116	444	.164
Tantalum	180.87	16.62	Ta	2995		.034
Tellurium	127.62	6.25	Te	452	1391	.047
Terbium	159.22		Tb			

## PROPERTIES OF THE ELEMENTS—continued

Name	Atomic Weight	Specific Gravity	Symbol	Melting Point °C	Boiling Point °C	Specific Heat
Thallium ... ..	204.41	11.91	Tl	303		.031
Thorium ... ..	232.11	11.3	Th	1702	1454	.029
Thulium ... ..	169.43		Tm			
Tin ... ..	118.71	7.29	Sn	232	2267	.054
Titanium ... ..	47.89	4.5	Ti	1798		.097
Tungsten ... ..	183.91	19.3	W	3388	4832	.035
Uranium ... ..	238.11	18.71	U	1687		.107
Vanadium ... ..	50.94	6.05	V	1722		.113
Xenon ... ..	131.31	3.5	Xe	-112	-109	
Ytterbium ... ..	173.06	5.5	Yb			
Yttrium ... ..	88.91	3.79	Y			
Zinc ... ..	65.39	7.12	Zn	419	913	.093
Zirconium ... ..	91.22	6.51	Zr	1856		.067

## CONVERSION TABLES

To change	Into	Multiply by	To obtain converse multiply by
Cubic Centimetres	Cubic Inches	0.06102	16.39
Calories	Kilogrammetres	427.0	0.00234
Dynes	Grammes weight	0.001019	980.39
Cubic Yards	Cubic Metres	0.7646	1.308
Cubic Inches	Litres	0.0164	61.0
B.Th.U.	Watt-hours	0.2931	3.41
Atmospheres	Lb./sq. in.	14.70	0.068
B.Th.U.	Calories	0.252	3.97
B.Th.U.	Foot Pounds	777.4	0.001285
Centimetres	Inches	0.3937	2.54
Cubic Feet	Cubic Metres	0.0283	35.31
Dynes	Poundals	0.000072	13825.52
Feet	Metres	0.305	3.281
Ergs	Foot-lb.	7.373 × 10 <sup>-8</sup>	1.36 × 10 <sup>7</sup>
Foot-lb.	Kilogrammetres	0.1384	7.23
Feet/sec.	Miles/hr.	0.68182	1.467
Feet/min.	Miles/hr.	0.01137	88.0
Feet/sec.	Metres/min.	18.288	0.0547
Grains	Grammes	0.0648	15.432
Gallons	Litres	4.546	0.2205
Foot-lb./sec.	Horse-power	0.0018	55.0
Feet/min.	Metres/sec.	0.00508	196.8
Horse-power	B.Th.U./min.	42.41	0.0236
Grammes/c.c.	Lb./cu. in.	0.03613	27.68
Gallons	Cubic Feet	0.161	6.211
Grammes	Ounces	0.03527	28.35
Grammes/sq. m.	Ounces/sq. yd.	0.0295	33.9
Inches	Millimetres	25.4	0.03937
Horse-power	Kilogrammetres/sec.	76.04	0.01315
Horse-power	Watts	746.0	0.00134
Joules	Watt seconds	1.0	1.0
Inches	Feet	0.0833	12.0
Imperial Gallons	U.S. Gallons	1.205	0.830
Kilocalories/Kilogramme	B.Th.U./lb.	1.80	0.55
Joules	Ergs	10 <sup>7</sup>	10 <sup>-7</sup>
Inches of Mercury	Lb./sq. in.	0.4902	2.04
Inches	Metres	0.0254	39.37
Inches	Yards	0.0277	36.0
Kilocalories	B.Th.U.	3968.0	0.000251
Kg./P.S.	Lb./h.p.	2.235	0.4475
K.Cal./cm. <sup>2</sup> /cm./hr./C°	B.Th.U./in./hr./F°	5.598	0.180
Kilogrammes	Lb.	2.205	0.454
Metres	Yards	1.094	0.914
Kilowatt Hours	Joules	36 × 10 <sup>8</sup>	27 × 10 <sup>-9</sup>
Kilogrammes/sq. cm.	Lb./sq. in.	14.22	0.0703
Kilogrammes	Tons	0.000981	1016.2
Kilometres	Miles	0.621	1.609
Poundals	Lb. weight	0.03107	32.15
Knots	m.p.h.	1.151	0.868
Kilowatts	Horse-power	1.3406	0.746
Litres	Pints	1.76	0.568
Metres/sec.	m.p.h.	2.24	0.447
Square Metres	Square Yards	1.197	0.8361
Square Centimetres	Square Inches	0.155	6.4516
Tonnes	Tons	0.9842	1.016

## CHEMICAL LAWS

**Heat of combustion** of a substance is the quantity of heat resulting from the combustion of 1 gram molecular weight of the substance.

**Hess' law of constant heat summation.**—The quantity of heat produced by a chemical reaction is similar, whether reaction takes place in one step or in a number of steps. All chemical reactions which commence with the same original constituents and finish with the same final constituent, free the same quantities of heat no matter by which process the final state is arrived at.

**Law of definite ratios.**—In every portion of all compound substances the ratio by weight of the constituent elements are always the same.

**Law of combining weights.**—The weights of elements combining with one another are called their "combining weights." Elements always combine either in the proportion of their combining weights or in simple multiples of these weights.

**Henry's law.**—The quantity of gas which a liquid will dissolve is in direct proportion to the pressure of the gas. This law is valid for all gases which do not unite chemically with the liquid solvent.

**Law of mass action.**—At a constant temperature the product of the active masses on one side of a chemical equation if divided by the product of the active masses on the opposite side of the equation result in a constant, no matter what the quantities of each substance available at the commencement of the reaction.

**Molecule.**—The minutest unit amount of matter which can exist by itself and retain all the properties of the original substance.

**Molecular volume.**—Is equal to the molecular weight divided by the density of the substance.

**Law of multiple proportions.**—Two elements can mix in more than one ratio by weight, but if this is so, the weights of an element which mix with a fixed weight of another element are always in simple proportion to each other.

**Molecular weight.**—The total value of the atomic weights of all the atoms in a molecule.

**Periodic law.**—The chemical and physical properties of elements are functions of their atomic numbers, and many of the properties are periodic functions.

## MECHANICS

**Acceleration due to gravity.**—The acceleration of a body falling in a vacuum without hindrance, the standard being equal to 980.665 cm./sec.<sup>2</sup> or 32.174 ft./sec.<sup>2</sup>.

**Gravitational acceleration at any elevation and latitude.**—If B is the latitude and T the elevation in centimetres the acceleration in cgs. units is equal to  $980.6 - 2.593 \cos 2B + .007 \cos^2 2B - 30.86 \times 10^{-7} T$ .

**Altitudes with the barometer.**—If A and B denote the corrected barometer readings at two points, C the average of the temperatures, D and E of the air at the two stations, F and G the water vapour tension at the two points, H the mean height above sea level, L the latitude, then the difference in height in centimetres is equal to :—

$$1,843,000 (\log A - \log B) (1 + .00367C) (1 + .0026 \cos 2L + .00002H + \frac{1}{2}M), \text{ where}$$

$$M = \frac{1}{2} \left( \frac{F}{A} + \frac{G}{B} \right)$$

A shortened formula, nearly correct for differences up to 1 Kilometre, is as follows :—

$$1,600,000 \frac{A-B}{A+B} (1 + .004C)$$

**Bernoulli's theorem.**—At any point in a pipe through which a liquid is flowing the sum of the potential energy, the kinetic energy and the pressure energy is a constant. If A is pressure, B height above a reference place, C density of the liquid, and D velocity of flow, then the constant is equal to

$$A + BC (32.174) + \frac{C(D^2)}{2}$$

**Principle of Archimedes.**—A body entirely or partly immersed in a liquid is buoyed up by a force equivalent to the weight of the liquid displaced. A body of volume B cm<sup>3</sup> immersed in a liquid of density f grams per cm<sup>3</sup> is buoyed up by a force in dynes, equal to fg (B). Its own weight of liquid is displaced by a floating body.

**Bulk modulus.**—The modulus of volume elasticity, Z is equal to —

$$\frac{A-B}{\frac{C-D}{C}}$$

where A, B, C, D are the initial and final pressures and volumes respectively

**Couple.**—Two equivalent and oppositely directed parallel but not colinear forces operating upon a body form a couple. The moment of the torque or couple is equal to the product of the one of the forces multiplied by the perpendicular distance between them.

**Specific cohesion or capillary constant** is equal to :—

$$\frac{2T}{32.174 (A-B)} = CD$$

where T is surface tension, A and B the densities of the two fluids, 32.174 the acceleration due to gravity, C the height of rise in a capillary tube of radius D

**Diffusion.**—If the concentration (mass of solid per unit volume of solution) at one face of a layer of liquid is A, and at the other face B, the thickness of the layer C and the area under consideration D, then the mass of the substance which diffuses through the cross-section E in time F is equal to :—

$$\text{where } K \text{ is the coefficient of diffusion. } KD \frac{(B-A) F}{C}$$

**Momentum conservation.**—If two bodies of masses A and B have, prior to impact, velocities C and D and after impact velocities E and F then:—

$$AE + BF = AC + BD$$

**Reduction of pressure at the side of a moving stream.**—If a liquid of density A moves with a velocity B the reduction of pressure caused by the movement is (neglecting viscosity), equal to

**Dimensional formulae.**—If mass, length, and time are reckoned basic amounts, the relation of other physical quantities and their units to these three can be expressed by means of a formula using the symbols L, M and T respectively, with appropriate exponents. e. g. the dimensional formula for surface would be expressed as (L<sup>2</sup>); or density as (L<sup>-3</sup>M) and momentum (LMT<sup>-1</sup>). Other basic amounts utilized in dimensional formulae can be shown as follows: T=temperature; E=dielectric constant of a vacuum; P=magnetic permeability of a vacuum.

### SCIENCE UNIT DIMENSION FORMULAE

L=Length. M=Mass. T=Time. H=Temperature. P=Magnetic Permeability of a Vacuum.

	L	M	T	H	P		L	M	T	H	P
Acceleration ...	0	0	-2	0	0	Magnetizing Force ...	-1/2	1/2	-1	0	-1/2
Action ...	2	1	-1	0	0	Magnetic Induction ...	-1/2	1/2	-1	0	1/2
Angle ...	0	0	0	0	0	Magnetic Moment ...	5/2	1/2	-1	0	1/2
Angular Acceleration ...	0	0	-2	0	0	Magnetic Permeability ...	0	0	0	0	1/2
Angular Velocity ...	0	0	-1	0	0	Mass Resistivity ...	-1	1	-1	0	1
Angular Momentum ...	2	1	-1	0	0	Magnetic Surface Density ...	-1/2	1/2	-1	0	1/2
Capacity ...	-1	0	2	0	-1	Magnetic Susceptibility ...	0	0	0	0	1
Capillarity ...	0	1	-2	0	0	Power ...	2	1	-3	0	0
Conductance ...	-1	0	1	0	-1	Period ...	0	1	0	0	0
Couple Torque ...	2	1	-2	0	0	Permeance ...	1	0	0	0	1
Compressibility ...	1	-1	3	0	0	Pressure ...	-1	-1	-2	0	0
Density ...	-3	1	2	0	0	Quantity of Magnetism ...	3/2	1/2	-1	0	1/2
Diffusion ...	2	0	-1	0	0	Quantity of Electricity ...	1/2	1/2	0	0	-1/2
Electric Current ...	1/2	1/2	-1	0	-1/2	Reluctance ...	-1	0	0	0	-1
Elasticity ...	-1	1	-2	0	0	Resistance ...	1	0	-1	0	1
Entropy ...	2	1	-2	-1	0	Specific Reluctance ...	0	0	0	0	-1
Electromotive Force ...	1/2	1/2	-2	0	1/2	Specific Resistance ...	2	0	-1	0	1
Electric Field Intensity ...	1/2	1/2	-2	0	1/2	Specific Heat of ...					
Elastic Moduli ...	-1	1	-2	0	0	Electricity Coefficients ...	3/2	1/2	-2	-1	1/2
Electric Potential ...	3/2	1/2	-2	0	1/2	Stress ...	-1	1	-2	0	0
Electric Surface Density ...	-3/2	1/2	0	0	-1/2	Strain ...	0	0	0	0	0
Frequency ...	0	0	-1	0	0	Speed ...	1	0	-1	0	0
Force ...	1	1	-2	0	0	Surface ...	2	0	0	0	0
Fluidity ...	1	-1	1	0	0	Surface Tension ...	0	0	-2	0	0
Heat Capacity ...	2	1	-2	0	0	Specific Volume ...	3	-1	0	0	0
Heat ...	2	1	-2	0	0	Temperature Resistance					
Inertia ...	0	1	0	0	0	Coefficient ...	0	0	0	-1	0
Inductance ...	1	0	0	0	1	Thermoelectric Power ...	0	1/2	-2	-1	1/2
Intensity of Magnetism ...	-1/2	1/2	-1	0	1/2	Time ...	0	0	1	0	0
Length ...	1	0	0	0	0	Thermal Capacity ...	0	1	0	0	0
Latent Heat ...	2	0	-2	0	0	Thermal Conductivity ...	1	1	-3	-1	0
Latent Heat of Vaporization ...	2	0	-2	0	0	Thermal Expansion ...	0	0	-1	0	0
Mass ...	1	1	0	0	0	Temperature ...	0	0	0	1	0
Momentum ...	0	1	-1	0	0	Viscosity ...	-1	1	-1	0	0
Moment of Inertia ...	2	1	0	0	0	Volume Conductivity ...	-2	0	1	0	-1
Mass Conductivity ...	1	-1	1	0	-1	Velocity ...	1	0	-1	0	0
Magnetic Potential ...	1/2	1/2	-1	0	-1/2	Volume ...	3	0	0	0	0
Magnetic Flux ...	3/2	1/2	-1	0	1/2	Weight ...	1	1	-2	0	0
Moment of Force ...	2	1	-2	0	0	Work Energy ...	2	1	-2	0	0
Moment of Momentum ...	2	1	-1	0	0						

**Force.**—Force is known in mechanics as the factor that tends to produce, modify or retard motion. Like weight, it also is measured in terms of ounces, pounds and tons.

**Weight.**—Weight is the measurement of the mass or quantity of a substance or body, and is expressed in terms of ounces, pounds, tons, etc.

**Time.**—Time in mechanics is the measure of time in which a definite amount of work is done. That is, it is a measure of the time in which a force acts upon a body. It is measured in terms of seconds, minutes and hours.

**Space.**—Space or distance, as considered in mechanics, is the measure of distance through which a force operates upon a body or substance. It is expressed in terms of inches, feet and miles.

**Work.**—Work, in mechanics, is the result of the force operating upon a body or substance multiplied by the space or distance through which the force operates. That is, it is the result of the weight or size of the force multiplied by the space or distance through which it operates.

**Power.**—Power, as used in reference to mechanics, is the result of force multiplied by distance and divided by time. It is used to designate the performance of a definite amount of work in a given time. The two terms Force and Power are not synonymous. Force defines the cause which tends to create or modify motion, whilst Power is the measure of force, distance and time.

**Units of Measurement.**—Force and weight are both reckoned in terms of ounces, pounds, tons, etc. Work is reckoned in terms of inch-pounds, foot-pounds, etc. Power is measured in inch-pounds per minute, foot-pounds per hour, etc.

**Kilowatt.**—The term kilowatt is the equivalent of 1,000 watts. It is used in electrical work as a measure of electrical force and is equal to 1.34 HP or 1 HP is equal to 0.746 kw.

**Horsepower.**—Horsepower, which is abbreviated in any of the following ways—HP, H.P., Hp, and hp., is the basic measure of power used in England, as a measure of the work or power of engines, boilers, turbines, electric motors and other similar machines and devices. It is equal to 33,000 ft.-lb. per min. Specifically, it means that 33,000 lb. have been moved through a distance of 1 ft. in 1 min.

When using the metric system, the equivalent of HP, is called the metric HP., and is equal to 75 kilogram-metres per second or equivalent to 32,500 ft.-lb. per min.

**Unit measure of force.**—The unit measure of force, as used in science, is the force that gives to a pound of matter an acceleration of 32.17 ft. per sec., or the force with which gravity attracts a pound of matter at 45° latitude at sea level.

**Centimetre-gram-second.**—In the centimetre-gram-second system (abbreviated C.G.S.) the force unit is that which operating on a mass of one gram, will produce in 1 sec. a velocity of 1 cm. per-sec. This is known as the 'dyne'.

**Resistance.**—As used in mechanics means anything which tends to oppose an acting force. When the body affected is balanced, the resistance is equivalent and opposite to the force.

**Inertia** is the property of a body which causes it to tend to remain in its existing state of rest or motion till it is operated upon by some force tending to alter its existing state.

**Velocity** is a measure of the rate of movement or speed of a body at any particular instant. It is measured in terms of inches or feet per sec., per min., or per hr.

**Energy** may be in the form of heat, or can be electrical, chemical, mechanical, etc. It is defined as the capacity for doing work and is measured in foot-pounds, like work.

No type of energy can be used up or produced without using up or producing the same quantity in another or the same form. Also, no type of energy can be used except by being produced again in another form. e.g. the energy resulting from the power and heat or steam in a turbine is expended in the form of motion, causing the turbine to produce useful work.

We will consider two of the many forms of energy. They are heat energy and mechanical energy. In these, energy exists in two forms. One of these is kinetic energy and the other, potential energy.

**Kinetic energy** is the energy possessed by a body in motion, e.g., steam has potential and kinetic energy. When confined in a boiler or pipe, the energy is potential, but on passing into an engine cylinder or into a turbine it expands, and so creates kinetic energy by the force of the expansion and the increase in its velocity.

**Potential energy**, or stored energy, is energy at rest, e.g., it is known that a body dropping to earth can be made to do work, therefore before it began to drop it held potential energy, or the self-contained power due to its weight and the force of gravity combined.

**Gravity** is the force which the attraction of the earth exerts upon a body, is different at different heights above sea level and depends on the weight of the body under consideration. But as a basis of measurement of gravity, it is the force which gives to a pound of matter an acceleration of 32.17 (32.2 approx.) ft. per sec at 45° latitude at sea level.

**Motion** is the change of position of a body. Velocity is the rate of motion. When the velocity of a body in motion is the same at every instant during which it takes place, then the motion is uniform motion. When the body's motion is changeable and is constantly increasing, this is called acceleration. Acceleration is the rate of speed at which the velocity of the body increases. If its motion is decreasing, it is called retarded motion, or deceleration.

**Momentum** is the product of the mass of a body multiplied by its acceleration. Mass is not merely weight, but is weight divided by g. Under standard conditions g equals 32.2, which is the standard value used in measuring mass. Momentum can be defined as the numerical equivalent of the pounds of force that stops the motion of a moving body in one second.

**Centre of gravity** is the centre of the magnitude of a mass of uniform density. In all cases it is that point about which, if the body were hung, all of its parts would be in balance, so that there would be no tendency to turn.

## TO FIND THE CENTRE OF GRAVITY OF A FIGURE OF ANY SHAPED OUTLINE

Should the figure be perfectly symmetrical about the centre of axis, the centre of gravity will always be found on that axis and the simplest method of finding the exact position of the centre of gravity on the said axis is by taking moments with reference to any convenient line at right angles to the known centre axis. Portion up the area of the figure into simple geometrical shapes the centre of gravity of which can be quite easily obtained. In the case of the illustration shown below, divide the outline into 3 rectangles, DEFG, HJKL and MNPR, calling the areas of these 3 rectangles, S, T and U respectively. Locate the centre of gravity of each of these triangles. Pick any axis such as ZZ so that it lies at 90° to the centre line VV and find distances s, t and u. Then the distance m of the centre of gravity of the whole figure from the axis ZZ is found from the following formula :—

$$m = \frac{Ss + Tt + Uu}{S + T + U} \text{ inches. See Fig. C.}$$

In each case let S, T, and U be the areas of the geometrical figures in sq. ins. and distances s, t, and u be in inches.

If on the other hand the figure outline is not symmetrical about any axis, then it is necessary, if one wishes to find the centre of gravity, to take moments from 2 separate convenient axes which we can call again VV ZZ as shown in the sketch below. The outline is then apportioned into simple geometrical figures of convenient shape whose centre of gravity is easily determinable as previously. The centre of gravity of the whole figure can then be found by use of the following formulas :—

$$n = \frac{Sa + Tb + Uc}{S + T + U} \text{ Inches}$$

In each case let S, T, and U be the area of the geometrical figures in sq. ins. and a, b, c, s, t, u, be in inches

$$m = \frac{Ss + Tt + Uu}{S + T + U} \text{ inches}$$

See Fig. D

From these 2 formulas the centre of gravity is accurately positioned with relation to the 2 axes.

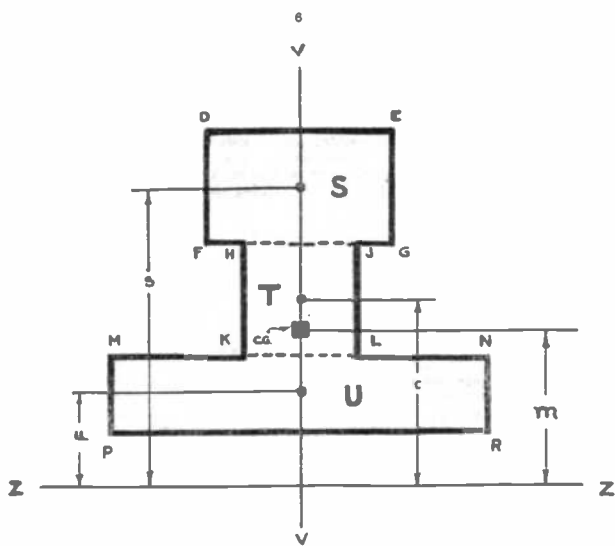


Fig. C.

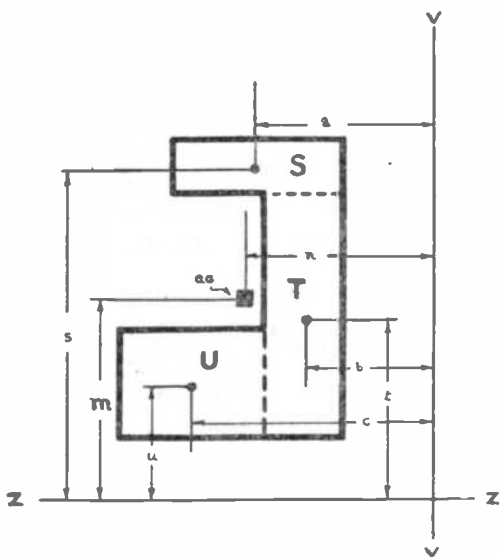


Fig. D

## NEWTON'S LAWS OF MOTION.

First law : Every body remains at rest, or in uniform motion in a straight line, unless it is forced by a force to alter its state of rest or motion. This is called inertia.

Second law : If a body is operated on by several forces, it is operated on by each of them as if the others did not exist, whether the body is resting or in motion, or change of motion is proportional to force applied and takes place in the direction of the line of action of the force.

Third law : For any action there is always an equal reaction, or, in other words, if a force operates to alter the state of rest or motion of a body, the body offers a resistance directly opposed and equal to the force.

*Formulas of motion :—*

A—force in pounds.  
 B—space or distance in feet.  
 C—time in seconds.  
 D—velocity in ft. per sec.  
 E—power in ft.-lb. per sec.  
 F—work in ft.-lb.  
 HP—horsepower.

The relations between each of these factors are given in the following formulas :—

$$\begin{aligned} A &= E \div D = F \div CD = 550 \text{ HP} \div D = F \div B \\ D &= E \div A = 550 \text{ HP} \div A = B \div C = F \div CA \\ \text{HP} &= DA \div 550 = F \div 550C = BA \div 550 \quad C = E \div 550 \\ F &= ACD = C(550 \text{ HP}) = BA = CE \\ C &= F \div DA = B \div D = BA \div 550 \text{ HP} = BA \div E \\ E &= F \div C = 550 \text{ HP} = DA = BA \div C \\ B &= CE \div A = 550 C \times \text{HP} \div A = D \div C = F \div A \end{aligned}$$

*Motion on inclined planes.*—A body falling down an inclined plane and moved only by the force of gravity, with friction neglected, has a velocity equivalent to that of the same body freely falling through a distance equal to the height of the plane.

*Falling bodies.*—Due to gravity alone, all bodies fall to earth with the same acceleration. Acceleration rises with latitude and drops with the elevation above sea level. Acceleration due to gravity in the metric system is calculated at 9.81 metres per second in one second at 45° latitude at sea level. This means that in every second the body is falling its velocity increases by 32.17 ft. or 9.81 m. per sec.

*Force of impact.*—When two inelastic bodies collide with each other, they will move together with the same velocity, and their momentum is equal to the sum of the momentum of each one at the moment of collision; (assuming in the foregoing that the two bodies are of different weights and that they do not meet in directly opposite directions, otherwise all motion would end.) Neglecting friction and resistance, imagine two inelastic bodies of the same mass and velocity and moving generally in the same direction were to collide, they would continue to move in a direction and at a rate of speed nearly equal to one half of their initial velocities and in a direction equivalent to one half of resultant of their combined directions of travel.

*Strain and elasticity.*—All materials are made up of atoms which are held in their respective relations to each other by inner atomic forces. When these atoms are displaced out of their normal state by the action of any force and then try to take up their normal positions, the substance is said to be under strain. A counterforce is exerted against the strain. The quality of a material which causes it to resume its original shape is known as its elasticity. Within normal limits all substances are elastic. It should be realised that the quantity of elasticity is one of degree rather than of kind and also that the term elasticity does not refer to the amount of deformation but to the completeness of recovery after taking away the distorting force.

*Modulus of elasticity.*—The modulus of elasticity or coefficient of elasticity is a quantity of the amount of deformation of a substance under stress. It is determined by dividing the unit stress applied to a substance by the deformation per unit produced by that stress or by dividing the stress by the strain.

*Stress.*—Stress is defined as the internal force in a substance which tends to counteract deformation when a force is exerted on the substance. Usually this is measured in pounds per square inch, since stress can also be regarded as the external force applied to the material. The effect of this force is called strain.

*Elastic limit.*—Elastic limit is defined as the maximum stress to which a material can be subjected without causing its permanent deformation. It is calculated particularly in reference to tension, compression, and shear stresses, which will be defined later.

*Yield point.*—In some ductile materials, when a load is applied in line with the axis of the centre of the substance, a point is reached when the material continues to elongate without any increase in the load applied. This is known as the yield point of the material.

*Tensile strength.*—The tensile strength of a substance is equal to the quantity of force which, steadily applied in a line with the axis of the centre of a substance, is sufficient to overcome the cohesion of the particles of the substance and pull it into two separate pieces. Following are the tensile strengths of various metals :—

Aluminium ...	25,000–35,000 lbs. per sq. in.
Gold ...	15,000–20,000 " " " "
Bronze... ..	60,000–80,000 " " " "
Rivet steel ...	55,000–65,000 " " " "
Steel ... ..	80,000–350,000 " " " "
Tin ... ..	6,000–15,000 " " " "

*Shearing strength* of a material is equal to the force which, if applied steadily at right angles to the central axis of the piece, is enough to cut the material into two pieces.



### BEAM STRENGTHS

A moment is defined as the measure of the tendency of a force to produce movement, and particularly around a given point as centre. A weight hung from the end of a beam produces a moment inclining to bend the beam. The bending moment changes according to how the beam is secured and loaded. Sketch A gives some common examples.

Handy formulas for reckoning the bending stress in lb. per sq. in. on a beam are:—

- (1) For rectangular beams:  $V = 6 K \div F^2 Y$  where  $V$  = stress;  $K$  = bending moment in in.-lbs.;  $F$  = depth of beam and  $Y$  = width of beam.  
 (2) For round beams  $V = 10.2 K \div F^3$  where  $F$  = diameter of beam.  
 All measurements are in pounds and inches.

*Examples.*—A round beam with one end built in is 20 ft. long. A weight of 1,500 lb. is hung in the middle. Find the bending moment.

The formula as shown on sketch A2, is  $K = PL \div 2$ .  $P = 1,500$  lb.  $L = 20 \times 12 = 240'$   
 $\therefore K = 1,500 \times 240 \div 2 = 180,000$  in. lbs.

A rectangular beam 6 in. wide, 10 in. deep and 10 ft. long is supported at both ends, with a weight of 400 lbs. hung from its centre. Find the bending moment and stress.

Referring to sketch A1,  $K = PL \div 4$ .  $P = 400$ .  $L = 10 \times 12 = 120'$ ,  
 therefore  $K = 400 \times 120 \div 4 = 12,000$  in. lbs.

and  $V = 6 K \div F^2 Y = 6 \times 12,000 \div 10^2 \times 6 = 120$  lb. per sq. in.

*Moments and centre of gravity.*—The centre of gravity can be accepted as the position where the effect of any object's weight is concentrated, or as its balancing point. A beam with weights suspended along it has a certain position on its length where the effects of these weights will balance each other.

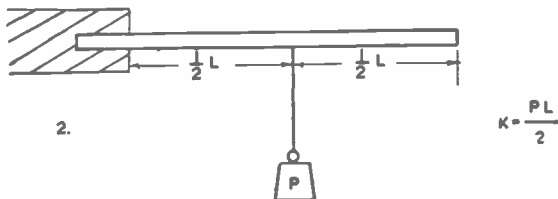
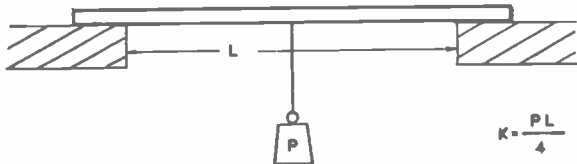
*Example.*—A bar 50 ft. long, 1,000 lb. in weight, and of uniform cross-section, has 4 weights hung on it. See Sketch A6. One of 100 lb. at one end, one 50 lb. at the other end, one of 150 lb. hung 10 ft. from the 50-lb. weight, and one of 200 lb. hung 15 ft. from the 100-lb. weight. Find the centre of gravity of the bar with weights.

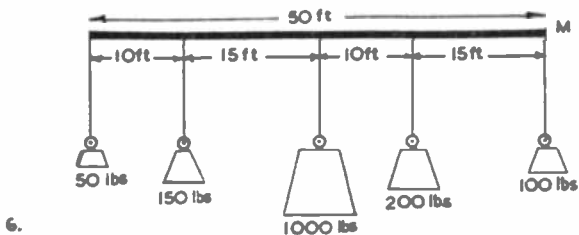
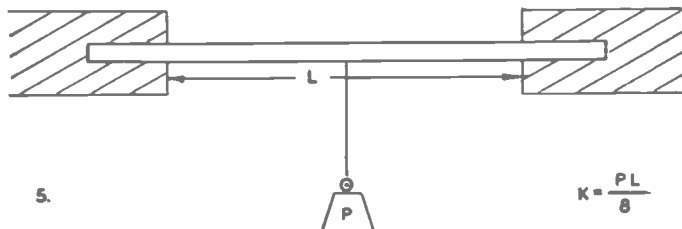
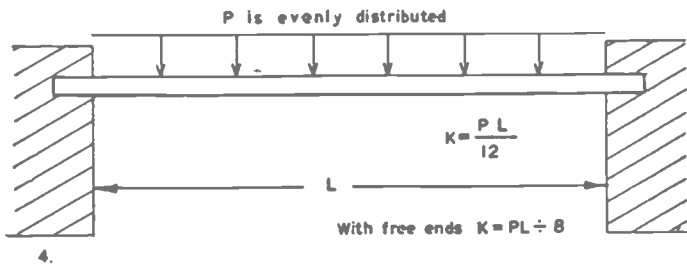
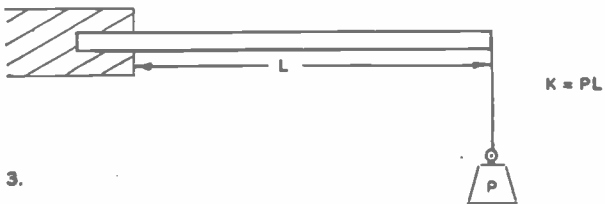
Since the bar is uniform, the point where its weight takes effect or its centre of gravity will be in the middle:  $50 \div 2 = 25$  ft. from each end, as shown.

First find the moments which tend to turn the bar around one of the ends as a centre. Taking the right hand end (M) as centre, and using the formula  $PL = K$ , find the moment of each weight in reference to M.  $100 \times 0 + 200 \times 15 + 1,000 \times 25 + 150 \times 40 + 50 \times 50 = 100 + 3,000 + 25,000 + 6,000 + 2,500 = 36,600 =$  sum of moments = 36,600 ft.-lbs. The total weight =  $100 + 200 + 1,000 + 150 + 50 = 1,500$  lbs.

Divide the sum of the moments by the sum of the weights:  $36,600 \div 1,500 = 24.4$  ft. from (M), which is the centre of gravity of the weighted bar.

Sketch A.





## RESULTANT AND COMPONENT FORCES

When a given force acts perpendicularly to the end of a beam, for example, a simple compressive stress is effected in the beam. But when a unit force acts at an angle to the beam (Sketch B1), both bending and compressive stresses are produced. The force  $F$  acting at  $A$  is divided into 2 parts,  $M$  acting to produce compression, and  $N$  acting to produce bending.

Representing the magnitude of  $F$  by the length  $AV$ , the magnitude of the components can be represented by extending  $AV$  to  $R$ , so that  $AV=AR$ , and then completing the parallelogram of forces  $ABRS$ . Lines  $AB$  and  $AS$  stand in the same proportion to  $AR$  as  $M$  and  $N$  do to  $F$ . The other parallelogram  $AXVY$  represents the forces acting against  $F$ , due to stress in the beam, and is equal to  $ABRS$ . Action always equals reaction, as stated in Newton's third law.

In Sketch B2, two forces are operating on the end of the beam. The 100-lb. force is perpendicular to the beam, and therefore produces only a simple bending stress. The 50-lb. force, acting at an angle, will have two components, as was the case in Sketch B1. Without considering this point, the problem is to find the quantity and direction of the force of reaction of the beam, as needed to balance the effect of these two forces.

The 50 and 100 lb. forces are the components of the resultant force,  $F$ . First draw  $OS$  and  $OT$  (Sketch B3) so that they are in ratio to the forces they are to show. The 100-lb. line will be 100 units long, the 50-lb. line 50 units long. (The unit may be any selected measure, or possibly, some fraction of an inch.) Then complete the parallelogram, two of which sides are  $OS$  and  $OT$ . The diagonal  $OW$  will represent the direction and proportional size of the necessary resisting force.

Since  $SW=OT$  then  $(OW)^2=(SO)^2+(SW)^2=(100)^2+(50)^2=12500$   
therefore  $OW=111.8$  approximately.

This value directly represents the number of pounds force, so the force required to balance the 100 lb. and 50 lb. is 111.8 lb.

Sketch B4 shows a case concerning a boom  $B,C$ , lifting a 10-ton weight. What is the tension on the topping lift  $BD$  and the compression or thrust on the boom?

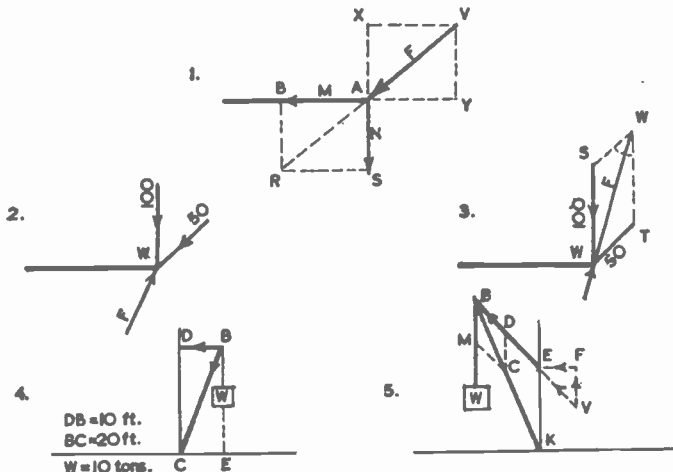
The first step in finding this division of forces is to complete the parallelogram of the two forces  $DBEC$ . Now  $DB=10$  ft.  $BC=20$  ft.  $DC=BE$ =length representing  $W$ .  $(DC)^2+(DB)^2=(BC)^2$  or  $DC^2=(BC)^2-(DB)^2=(20)^2-(10)^2=(400)-(100)=300$  therefore  $DC=17.32$ . Since the sides of the triangle are directly proportional to the forces set up, the proportion  $17.32 : 10 :: 10 : X$ .  $17.32 X=100$  therefore  $X=5.7$  tons approximate tension on the topping lift. For the second answer  $17.32 : 20 :: 10 : X$  therefore  $17.32 X=200$  and  $X=11.4$  tons thrust on the boom.

A more direct method of measuring component forces is indicated by Sketch B5. The boom  $BK$  is lifting the weight  $W$ . Find the tension on  $BE$ , and thrust on  $BK$ . Also find the bending stress on the mast  $EK$ .

Using the scale such as 1-10th in.=1 ton, measure off on  $BW$  enough units to equal the number of tons ( $W$ ). This gives the length  $BM$ . Draw  $MC$  parallel to  $BE$ . Then draw  $CD$  parallel to  $BM$ , completing the parallelogram of forces.  $BE$  represents thrust on boom,  $BD$  tension on topping lift. All that is required is to measure  $BC$  and  $BD$  by the same scale as was used in drawing  $BM$  and this gives the number of tons of thrust and tension.

To find the bending stress on the mast  $EK$  is a question of resolving the tension  $BD$  into its two parts. Extend  $BE$  to  $V$ , so that  $BD=EV$ . Then complete the triangle of forces, the other two sides being from  $V$  a line parallel to  $KE$  and from  $E$  a line parallel to the base against the scale as before,  $FV$  will give the tons tension upward on mast.

Sketch B.



**Ultimate tensile strength.**—When a material is under tension, a point is arrived at when the load increases past the yield point and unit deformation and stress will grow until the final load-carrying capacity of the material is reached. This limit is called its ultimate tensile strength.

**Weldable.**—A material is weldable when two pieces of it can be united or joined together by welding in a forge, or by other welding methods.

**Ductility.**—The ductility of a material is that characteristic which causes it to stay extended after having been drawn out by a tensile force. The more the extension which can be produced the higher the ductility of the material.

**Malleable.** A material is malleable in ratio to the amount to which it can be rolled, hammered, or forged—etc., without breaking.

**Thermal conductivity.**—Thermal conductivity is the quantity of the ability of a material to conduct heat, just as electrical conductivity is the quantity of its ability to conduct electricity.

**Toughness.**—Toughness is the quantity of the working, bending and other operations that a material can undergo without damage to its structure.

**Hardness.**—The hardness of a material is an amount used, particularly in the case of steel, to determine strength, ductility, malleability, etc. It may be defined as the measure of the ability of a material to resist denting, scratching, or any other form of penetration (not shattering) by another substance. Degree of hardness is an important factor in tool steel or diamonds, etc.

**Coefficient of expansion.**—The coefficient of expansion of a material is the measure of the amount of linear expansion that takes place per degree change of temperature.

**Brinell method of testing hardness.**—In the Brinell method a hardened steel ball is pressed into a flat surface of the test sample, thus forming a slight indentation in the test piece. A load of 500 kilograms is applied to the ball for testing soft metals, 3,000 kilograms for harder metals, or 100 kilograms for very soft metals such as lead, and the pressure is maintained on the ball for about two minutes maximum. The area of the indentation is then calculated and the pressure applied is divided by this area to get the Brinell hardness number.

**Scleroscope method.**—The scleroscope is a vertical glass tube in which a dull-pointed, hardened steel hammer in the shape of a cylinder slides freely. The tube is placed on the test sample and the hammer dropped through the tube from a height of about 10 inches. The height of rebound is measured against the graduations on the tube, which is divided into 140 parts. The number of the highest graduation to which the hammer rebounds is thus the scleroscope hardness number. For glass it is 125-135, mild steel 24-32, wrought iron 14-18, soft brass 10-12 and lead 2.

**Conversion formula.**—A formula has been adopted for changing scleroscope number to Brinell number. It is  $B \text{ equals } 5.5 S - 28$ , where  $B$  equals Brinell number and  $S$  equals scleroscope number.

**Fatigue.**—Fatigue is a term applied to materials after they have lost some of their natural ability to resist fracture, due to the repeated application of forces, or, a piece of metal may be said to be tired when it snaps suddenly, for example, after having been bent a number of times at one place. Fatigue is believed to arrive from having some of the particles of the material strained beyond their elastic limit, thus starting small cracks or fissures. Corrosion quickens fatigue to a very great extent.

**Creep or flow.**—Creep is inelastic movement in metals, similar to the flow of fat or grease at moderate temperatures when under only a slight force. Nearly all metals will creep under the correct conditions. When temperature is high, creep occurs under comparatively small stresses, and vice versa. Since creep will continue indefinitely, the deformation caused by it is of importance in regard to parts of machinery under heavy loads and high temperatures.

**Brittleness.**—Brittle materials are those which will break under a load after only a slight deformation. Brittleness is relative only because there is no material which does not have some amount of elasticity. Brick and glass and china are good examples of brittle materials.

**Safety factor.**—The safety factor of a material is found by dividing its breaking strength by the permissible stress which will be applied to it, or, the safety factor shows how much greater the strength of the material must be than the force which will normally be applied to it. The safety factor of cast iron varies from 5 to 25. The safety factor of steel varies from 6 to 18.

**Static and energy loads.**—Stress-producing loads which are applied gradually, are known as static or loads applied suddenly, as a weight hung quickly on a bar, or loads applied when in motion are called energy or loads. The first effect of an energy load is to produce a stress much higher than that produced by a static load. For loads applied in motion, the stress and deformation produced on impact is still greater, rising with the speed of the load, but if the elastic limit of the material under stress is not passed, the surplus energy of the energy load is changed into heat, and the stress and deformation drops to the amount which an equal static load would have produced.

## LEVERS

The lever is used to operate on a pressure or large weight by application of a smaller one. Levers are in three classes—(a) where the weight is between the fulcrum and the force; (b) where the fulcrum is between the weight and the force; and (c) where the force is between the fulcrum and the weight. The following formulas will enable all calculations on levers to be effected.

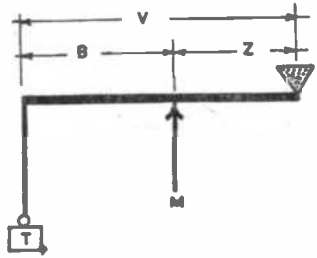
## LAWS OF LEVERS

$$M : T = V : Z \quad V = \frac{M \times Z}{T}$$

$$M \times Z = T \times V \quad T = \frac{M \times Z}{V}$$

$$M = \frac{T \times V}{Z} \quad Z = \frac{T \times V}{M}$$

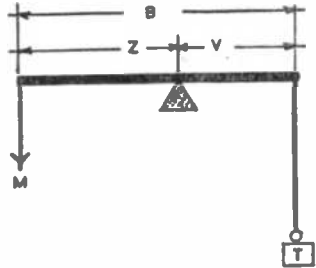
$$Z = \frac{T \times B}{M - T} \quad V = \frac{M \times B}{M - T}$$



$$M : T = V : Z \quad M \times Z = T \times V \quad Z = \frac{T \times B}{T + M}$$

$$M = \frac{T \times V}{Z} \quad Z = \frac{T \times V}{M} \quad T = \frac{M \times Z}{V}$$

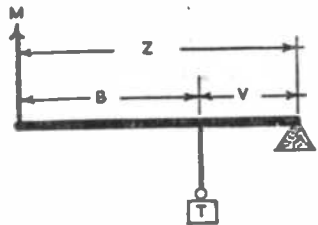
$$V = \frac{M \times Z}{T} \quad V = \frac{M \times B}{T + M}$$



$$M = \frac{T \times V}{Z} \quad M \times Z = T \times V \quad V = \frac{M \times B}{T - M}$$

$$V = \frac{M \times Z}{T} \quad T = \frac{M \times Z}{V} \quad Z = \frac{T \times B}{T - M}$$

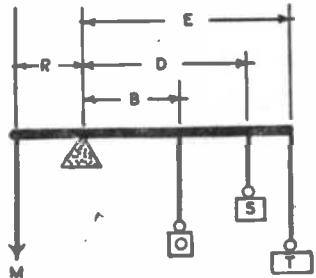
$$M : T = V : Z \quad Z = \frac{T \times V}{M}$$



$$R = \frac{O \times B + S \times D + T \times E}{M}$$

$$M \times R = O \times B + S \times D + T \times E$$

$$M = \frac{O \times B + S \times D + T \times E}{R}$$



**Critical speed.**—In all rotating bodies the centre of gravity of the weight of both wheel and shaft must be exactly in the centre of the shaft if a true running balance is to be had. If the centre of gravity of the weight of both wheel and shaft is not in the centre line of the shaft, there is a tendency toward deflection in the shaft as it turns at high speed. This deflection is in the direction of the side of the mass which is the heavier, and the centrifugal force generated by this heavier side will be more than that of the lighter side. This force increases as the turning speed increases until a point is achieved when there is excessive vibration. Over this speed the unbalanced mass will again turn smoothly. The rate of speed at which this excessive vibration ends is known as the critical speed.

Critical speed can be defined as the speed in turning bodies which, because of centrifugal force, would cause them to burst. A flywheel can burst because of an excessive speed or due to centrifugal force which is greater than the strength of the arms supporting the rim of the wheel.

**Balance** generally has reference to the equilibrium of turning bodies. It is considered in two forms: static balance and dynamic balance. Static balance is used as a measure of the state of balance of turning bodies about a fixed axis, while the bodies are motionless; e.g., the static balance of a roller is found by mounting the roller on a shaft known to be in perfect balance and then pulling the shaft between fixed centres. If the roller and shaft are in perfect equilibrium there is no tendency toward turning in any direction; but if the wheel is unbalanced there is a tendency for the heavier side of the roller to cause both it and the shaft to turn until the heavier side is at the absolute bottom of the mass.

To check for dynamic balance, as with the roller and shaft mentioned above, the shaft is placed between centres and is turned. If the mass is unbalanced this is shown by vibration, due to variation of centrifugal force. Such vibrations are measured with an indicator. To balance such a roller, counterweights may be added to its lighter side, or weight can be taken off from its heavier side.

### INCLINED PLANE

Application of the work formula makes clear the advantage of using the inclined plane for raising weights. The formula used to find the force necessary for raising a given weight is,  $F$  equals  $W$  multiplied by the height of plane divided by the length of plane.

Assume a plane 80 ft. long and 10 ft. high at the high end, and a 200-lb. weight which is to be pulled up it. Neglecting friction, what force will be needed to move the weight?

$F$  equals 200 multiplied by 10 divided by 80 equals 25-lb.

The work equals  $F$  multiplied by distance moved, equals 25 multiplied by 80 equals 2,000 ft.-lb.

To prove this, calculate the work which would be expended in elevating the weight vertically to the same height: 200 multiplied by 10 equals 2,000 ft.-lb.

A coefficient of friction always exists. Assume this coefficient to be 15 per cent. in this case. Then multiply the weight moved by this coefficient to calculate the extra force that is to be used.

200 multiplied by .15 equals 30 lb. The correct force is therefore: 25 plus 30 which is equal to 55-lb.

### FORMULAS FOR PENDULUMS

$M$  = Length of pendulum in inches or distance from point of suspension to centre of oscillation.

$B$  = Time in seconds for  $S$  oscillations.

$S$  = Number of single oscillations in time  $B$ .

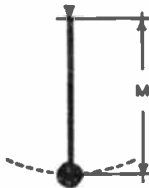


Fig. 1

Fig. 1. Simple Pendulum

$$S = \frac{6.25B}{\sqrt{M}}$$

$$M = \frac{39.1(B^2)}{S^2}$$

$$B = \frac{S\sqrt{M}}{6.25}$$

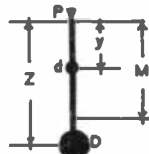


Fig. 2

Fig. 2. Compound Pendulum

$d$  and  $D$  = weight in lbs.  $P$  = point of Suspension

$$M = \frac{z^2D + y^2d}{zD + yd}$$

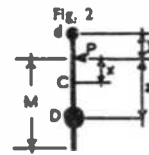


Fig. 3

Fig. 3. Compound Pendulum

$d$  and  $D$  = weight in lbs.  $P$  = Point of Suspension.  $C$  = Centre of Gravity.

$$M = \frac{z^2D + y^2d}{x(D + d)}$$

$$x = \frac{zD - yd}{D + d}$$

### CONICAL PENDULUM

Should a weight, hung by a line, rotate at constant speed about the periphery of a circle in a horizontal plane, this weight forms what is known as a conical pendulum and it is maintained in balance by three specific forces. Firstly, the force of gravity. Secondly, the tension in the line and, thirdly, centrifugal force.

Let  $S$  be equal to the radius of the circular path in feet which the weight follows. Let  $P$  be the height in feet of the plane in which the weight rotates from the actual point from which it is hung. Let  $M$  be the speed in feet per second of the centre of gravity of the weight and, finally, let  $Y$  be the time in seconds for one revolution. Then the following formulas are derived:—

$$Y = \frac{6.28S}{M} = 6.28 \sqrt{\frac{P}{g}} \quad P = \frac{S(Y^2)}{4(3.14^2)} = .815(Y^2) \quad g = 32.174$$

**Pendulum.**—For a simple pendulum of length  $P$  and for a small amplitude, the complete period in time is equal to:—

$$6.28 \sqrt{\frac{P}{32.174}} \quad \text{and} \quad 32.174 = 4(3.14^2) \frac{P}{\text{Time}^2}$$

Time will be in seconds if  $P$  is in cm and gravity in cm per sec.<sup>2</sup>

If the period is  $B$  for an arc of  $V^\circ$ , the time of vibration in an infinitely small arc is approximately equal to:—

$$\frac{B}{1 + \frac{1}{2} \sin^2 \frac{V}{4}}$$

For a globe hung by a line of negligible mass where  $M$  is the distance from the knife edge to the globe's centre whose radius is  $R$ , the length of the equivalent simple pendulum is equal to:—

$$M + \frac{2(R^2)}{5M}$$

**Compound pendulum.**—If a body of mass  $M$  be hung from a point about which its moment of inertia is  $P$  with its centre of gravity a distance  $H$  below the point of hanging, the period is equal to time in seconds of:—

$$6.28 \sqrt{\frac{P}{32.174MH}}$$

**Period in uniform motion** is the time needed for one complete rotation and in oscillatory motion it is the time needed for a whole oscillation.

**Centrifugal force.**—A weight moving in a circular path about a fixed point as a centre and held to that centre by a cord or arm exerts an amount of force upon the cord or arm. This force which attempts to make the weight move out in a straight line or "fly off at a tangent" is known as centrifugal force.

### FORMULAS FOR ROTARY MOTION

**A** equals force in lbs. acting in direction of tangent.

**B** equals power in ft.-lbs. per sec.

**C** equals velocity in ft. per sec.

**D** equals distance passed in feet by point of application of force **A**.

**E** equals time in seconds.

**F** equals work in ft.-lbs.

**H** equals R.P.M.

**G** equals radius of revolution (radius to point of application of force **A** in feet).

**M** equals total number of revs. in time **E**.

**N** equals horse power.

$$A = \frac{60B}{6.28(GH)} = \frac{9.55B}{GH} = \frac{5252N}{GH} = \frac{9.55F}{GHE}$$

$$B = \frac{6.28(GHA)}{60} = \frac{AGM}{.159E} = \frac{GHA}{9.55}$$

$$F = \frac{6.28(AGHE)}{60} = 6.28(GMA) = \frac{AGHE}{9.55}$$

$$N = \frac{AGM}{87.5E} = \frac{AGH}{5252}$$

$$C = \frac{6.28(GH)}{60} = .105GH$$

$$H = \frac{60C}{6.28G} = \frac{5252N}{AG} = \frac{9.55C}{G}$$

$$B = \frac{GHA}{9.55} = \frac{AGM}{.159E} = \frac{6.28(GHA)}{60}$$

$$D = \frac{GHE}{9.55} = 6.28(GM) = \frac{6.28(GHE)}{60}$$

$$M = \frac{D}{6.28G} = \frac{.159(BE)}{AG} = \frac{F}{6.28(GA)} = \frac{87.5(EN)}{AG}$$

$$G = \frac{9.55B}{AH} = \frac{60C}{6.28H} = \frac{9.55C}{H} = \frac{9.55F}{AHE} = \frac{5252N}{AH}$$

## FORMULAS FOR RETARDED OR ACCELERATED MOTION

- A equals force in lbs. causing acceleration acting on a body free to move.  
 B equals time in seconds during which A acts on the body.  
 C equals constant acceleration in ft. per second due to A.  
 D equals final velocity at end of time B or uniform velocity of a moving body.  
 E equals distance in ft. passed through whilst A acts on the body.  
 F equals weight of moving body in lbs.  
 G equals average power exerted during time B in ft.-lbs. per second.  
 H equals work in ft.-lbs. or energy concentrated in moving body.  
 g equals 32.16 equals gravity due to acceleration.

$$E = \frac{D^2}{2C} = \frac{BD}{2} = \frac{BG}{A} = \frac{C(B^2)}{2} = \frac{gH}{CF} = \frac{gA(B^2)}{2F} = \frac{H}{A}$$

$$B = \frac{D}{C} = \sqrt{\frac{2EF}{gA}} = \sqrt{\frac{2HF}{g(A^2)}} = \sqrt{\frac{2E}{C} \cdot \frac{H}{G}} = \frac{DF}{gA}$$

$$H = BG = AE = \frac{g(A^2B^2)}{2F} = \frac{F(D^2)}{2g} = \frac{ABD}{2} = \frac{CFBD}{2g} = \frac{AC(B^2)}{2}$$

$$A = \frac{DF}{gB} = \frac{CF}{g} = \sqrt{\frac{2FG}{gB}} = \frac{H}{E} = \frac{BG}{E} = \frac{2EF}{g(B^2)} = \frac{2H}{C(B^2)} = \frac{F(D^2)}{(gE)2}$$

$$D = \sqrt{2CE} = \frac{gAB}{F} = \sqrt{\frac{2gH}{F}} = \sqrt{\frac{2gAE}{F}} = \sqrt{\frac{2gBG}{F}} = BC = \frac{2E}{B}$$

$$G = \frac{gB(A^2)}{2F} = \frac{A(D^2)}{2CB} = \frac{2F(E^2)}{g(B^2)} = \frac{F(D^2)}{2gB} = \frac{AE}{B} = \frac{H}{B}$$

$$F = \frac{2gH}{D^2} = \frac{gA(B^2)}{2E} = \frac{gH(B^2)}{2(E^2)} = \frac{gC(B^2)}{2(E^2)} = \frac{2gAE}{D^2} = \frac{gA}{C} = \frac{gAB}{D}$$

$$C = \frac{2H}{A(B^2)} = \frac{gH}{EF} = \frac{gBG}{EF} = \frac{2E}{B^2} = \frac{D^2}{2E} = \frac{D}{B} = \frac{gA}{F}$$

### CENTRIFUGAL FORCE FORMULAS

- A equals centrifugal force in lbs.  
 B equals weight of rotating body in lbs.  
 C equals velocity of rotating body in ft. per sec.  
 D equals radius of gyration.  
 E equals R.P.M.  
 g equals 32.16.

$$B = \frac{ADg}{C^2} = \frac{2933A}{D(E^2)} \quad E = \sqrt{\frac{2933A}{DB}} \quad C = \sqrt{\frac{ADg}{B}}$$

$$D = \frac{2933A}{B(E^2)} = \frac{B(C^2)}{Ag} \quad A = .0003BD(E^2) = \frac{B(C^2)}{gD} = \frac{BD(E^2)}{2933}$$

### FORMULAS FOR ACCELERATING ROTARY MOTION

- A equals force in lbs., acting tangentially at end of radius R.  
 R equals radius at end of which A is applied in feet.  
 B equals radius of gyration in feet.  
 C equals time of acceleration in seconds.  
 D equals revolutions per minute at end of time C.  
 E equals total number of revs. in time C.  
 F equals weight of revolving body in lbs.  
 G equals work in ft.-lbs. or energy concentrated in rotating body.  
 g equals 32.16.

From the previous formula for accelerated or retarded motion

A equals DF from this the following formula is reached :

$$\frac{A}{gB}$$

$$A = \frac{6.28BDF}{60gC} \text{ and } AR = \frac{FB(6.28BD)}{60gC} = \frac{F(6.28(B^2)D)}{60gC}$$



Therefore by substitution

$$D = \frac{120E}{C} - \frac{76.6}{B} \sqrt{\frac{G}{F}} - \frac{307.1(ACR)}{F(B^2)} - \frac{60G}{3.14RAC}$$

$$B = \sqrt{\frac{2.56AR(C^2)}{EF}} = \sqrt{\frac{307.1(ARC)}{EF}} = \frac{337G}{D\sqrt{FDCAR}} = \frac{.26GC}{E\sqrt{BFAR}}$$

$$A = \frac{.003FD(B^2)}{CR} = \frac{G}{6.28RE} = \frac{.39FE(B^2)}{R(C^2)} = \frac{60G}{3.14RDC}$$

$$E = \frac{G}{6.28RA} = \frac{CD}{120} - \frac{.64C}{B} \sqrt{\frac{G}{F}} - \frac{2.56AR(C^2)}{F(B^2)}$$

$$C = \sqrt{\frac{.39FE(B^2)}{AR}} = \frac{.25B\sqrt{FG}}{AR} = \frac{.003FD(B^2)}{AR} = \frac{60G}{3.14RDA}$$

**Simple harmonic motion.**—Periodic oscillatory movement in a straight line in which the force restoring is in ratio to the displacement. If a point move uniformly in a circle, the movement of its projection on the diameter (or any straight line in the same place) is simple harmonic motion.

If R is the radius of the reference circle, W the angular velocity of the point in the circle, P the angular displacement at the time M after the particle passes the centre point of its path, the linear displacement K is equal to :—

$$R \sin WM = R \sin P$$

The velocity S at the same moment is equal to :—

$$W\sqrt{R^2 - K^2} = RW \cos P$$

The force Y for a mass L is equal to :—

$$-LW^2K = -\frac{4(3.14^2)LK}{U}$$

The period U is equal to :—

$$6.28 \sqrt{\frac{K}{A}}$$

The acceleration A is equal to :—

$$-W^2K$$

In the above formulas the cgs system requires that K and R be in cm., S in cm. per sec., U in sec., P in radians, L in grams, A in cm. per sec.<sup>2</sup> and W in radians per sec.

### FORMULAS FOR FALLING BODIES

x = velocity of falling body at end of time T in feet per second.

T = time the body is falling in seconds.

K = distance in feet which the body falls through in the Tth second.

M = distance in feet which the body falls through in T seconds.

g = gravity = 32.2.

$$T = \frac{2M}{x} - \frac{x}{g} = \sqrt{\frac{2M}{g}} - \frac{K}{g} + \frac{1}{2} = \frac{\sqrt{M}}{4.01} \quad K = g(T - \frac{1}{2})$$

$$x = \frac{2M}{T} = gT = \sqrt{2gM} = 8.02\sqrt{M}$$

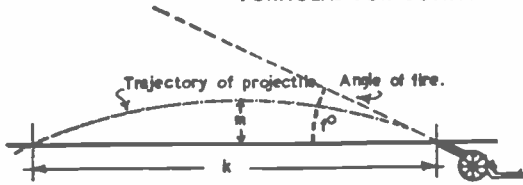
$$M = \frac{x^2}{64.32} = \frac{xT}{2} = \frac{gT^2}{2}$$

**Sensitiveness of a balance.**—If the three knife edges of a balance lie on a straight line, then W is the weight of the beam, H the distance of the centre of gravity below the knife edge, K the length of the balance arms, and V a small mass added to one side, the deflection D produced is equal to :—

$$\tan D = \frac{KV}{WH}$$

**Poisson's ratio** is the ratio of the collateral construction per unit dimension of a bar of constant cross-section to its elongation per unit length, when exposed to a tensile stress.

## FORMULAS FOR GUNNERY



$x$  = velocity of projectile in feet per sec.  
 $t$  = time.  
 $g$  = gravity = 32.2.  
 $k$  = travel of projectile in feet.  
 $f$  = angle in degrees of fire.  
 $m$  = height attained by projectile in feet.

$$t = \frac{2x(\sin f)}{g} \quad k = \frac{2(x^2)(\sin f)(\cos f)}{g} \quad m = \frac{x^2(\sin^2 f)}{2g}$$

**Coefficient of friction.**—The friction coefficient between two surfaces is the ratio of the force needed to move one surface over the other as compared to the total force which tends to press the two together.

If  $B$  is the force required to move one surface over another and  $M$  the force pressing the surfaces together, the coefficient of friction is equal to :—

$$\frac{B}{M}$$

**Rotation energy.**—If a mass, whose moment of inertia about an axis is  $D$ , turns with angular velocity  $W$  about this axis, the kinetic energy of rotation is equal to :—

$$\frac{DW^2}{2}$$

The energy can be expressed in ergs if  $D$  is in grams  $\text{cm}^2$  and  $W$  in radians per sec.

**Kepler's laws.**

- i. The planets rotate around the sun in ellipses, the sun being situated at one focus.
- ii. The radius vector connecting each planet with the sun passes through equal areas in equal times.
- iii. 3rd. powers of the mean distances of the planets from the sun are in ratio to the squares of their times of rotation about the sun.

**Hooke's law.**—The ratio of the stress to the strain produced is constant, within the elastic limit of any body.

**Mass by weighing on a balance with unequal arms.**—If  $A$  is the value for one side,  $B$  the value for the other, the true mass is equal to :—

$$\sqrt{AB}$$

**Triangle or polygon of forces.**—If three or more forces operating at the same point are in balance, the representing vectors form, when added, a closed figure.

**Composition of vectors.**—When the angle between two vectors is  $C^\circ$  and their size  $A$  and  $B$ , their resultant is equal to :—

$$\sqrt{A^2 + B^2 + 2AB \cos C}$$

**Moment of inertia.**—The extent of the effectiveness of mass in revolution. In the turning of a rigid body not only the body's mass, but also the distribution of the mass about the axis of turning decides the alteration in the angular velocity produced from the action of a set torque for a set time. Moment of inertia in rotation resembles mass (inertia).

If  $A, B, C, D$ , etc., represent the masses of infinitely small particles of a body,  $E, F, G, H$ , etc., their respective distances from the axis of rotation, the moment of inertia about this axis will be :—

$$(AE^2 + BF^2 + CG^2 + DH^2 + \dots)$$

**Moment of Force or torque** is the efficaciousness of a force to bring about revolution about an axis and is calculated by the product of the force and the perpendicular distance from the line of action of the force to the axis.

## ELASTIC MODULI

**Young's modulus by stretching.**—If an elongation  $R$  is produced by the weight of the mass  $m$ , in a wire of length  $P$ , and radius  $W$ , the modulus is equal to

$$\frac{32.174mP}{3.1416R(W^2)}$$

**Young's modulus by bending with bar supported at each end.**—If a flexure  $K$  is produced by the weight of mass  $m$ , placed midway between the supports separated by a distance  $P$ , for a rectangular bar with vertical dimensions of cross-section  $V$  and horizontal dimension  $C$ , the modulus is equal to :—

$$\frac{32.17m(P^3)}{4KC(V^2)}$$

The modulus for a bar of radius  $W$  is equal to :—

$$\frac{32.17m(P^3)}{37.699K(W^4)}$$

The modulus for a bar supported at one end is equal to :—

$$\frac{4mP^3(32.174)}{9.425K(W^4)}$$

The modulus for a rectangular bar supported at one end as mentioned above is equal to :—

$$\frac{4mP^3(32.174)}{KC(V^2)}$$

*Rigidity modulus.*—If a torque  $C (= mgx)$  results a twist of  $P$  radians in a bar of length  $T$  and radius  $R$ , the modulus is equal to :—

$$\frac{2CT}{3.1416P(R^4)}$$

*Coefficient of restitution.*—Two bodies moving in the same straight line, with velocities  $A$  and  $B$  respectively hit, and after impact move with velocities  $C$  and  $D$ . The coefficient of restitution is then equal to :—

$$\frac{D-C}{B-A}$$

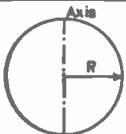
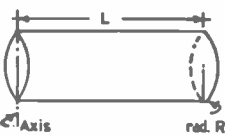

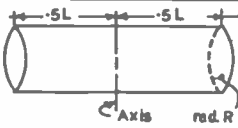

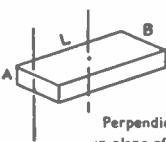
*Elasticity modulus* is the stress needed to effect unit strain, which can be an alteration of length (Young's modulus) : a shear or twist (modulus of torsion or modulus of rigidity), or an alteration of volume (bulk modulus), expressed in dynes per square centimetre. Dimensions, the same as that of stress.

### MOMENT OF INERTIA FOR SOLID BODIES

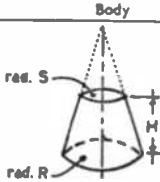
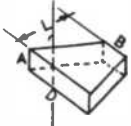
The mass of the body is indicated by  $M$

Axis	Body	Moment of Inertia
Normal to the length at one end.	Uniform thin rod.	$\frac{ML^2}{3}$
Any diameter	Spherical shell, very thin, mean radius, $R$	$M\frac{2R^2}{3}$
Any diameter	Spherical shell, external radius, $R$ internal, radius $S$	$M\frac{2(R^2-S^2)}{5(R^2-S^2)}$
Through centre perpendicular to the axis of the figure (transverse diameter)	Right circular cylinder of radius $R$ length $L$	$M\left(\frac{R^2}{4} + \frac{L^2}{12}\right)$
Through centre parallel to $B$	Thin rectangular sheet, sides $A$ and $B$	$M\frac{A^2}{12}$
Longitudinal axis	Elliptic cylinder, length $L$ transverse semiaxes $A$ and $B$	$M\left(\frac{A^2+B^2}{4}\right)$
Longitudinal axis of the figure	Hollow circular cylinder, length $L$ , external radius $R$ , internal radius $S$	$M\frac{(R^2+S^2)}{2}$
Along any diameter	Thin circular sheet of radius $R$	$M\frac{R^2}{4}$
Longitudinal axis of the figure	Thin cylindrical shell, length $L$ , mean radius $R$	$MR^2$
Through centre perpendicular to face $AB$ , parallel to edge $C$	Rectangular parallelepiped, edges $A$ , $B$ , and $C$	$M\frac{A^2+B^2}{12}$
Normal to the length, at the centre	Uniform thin rod	$M\frac{L^2}{12}$
Transverse diameter	Hollow circular cylinder, length $L$ , external radius $R$ , internal radius $S$	$M\left(\frac{R^2+S^2}{4} + \frac{L^2}{12}\right)$
Through the centre perpendicular to the sheet	Thin rectangular sheet, sides $B$ and $C$	$M\frac{B^2+C^2}{12}$
Axis $2E$	Ellipsoid, axes $2E$ , $2F$ , $2G$	$M\frac{E^2+G^2}{5}$
Any diameter	Sphere, radius $R$	$M\frac{2R^2}{5}$
Axis of the figure	Right cone, altitude $A$ , radius of base $R$	$.3MR^2$
Through centre normal to plane of ring	Thin circular ring. Plane figure formed by two concentric circles of radius $R$ and $S$	$M\frac{R^2+S^2}{2}$
Transverse diameter	Hollow circular cylinder, length $L$ , very thin, mean radius $R$	$M\left(\frac{R^2}{2} + \frac{L^2}{12}\right)$
Normal to the plate through the centre	Thin circular sheet of radius $R$	$M\frac{R^2}{2}$
Longitudinal axis of the solid	Right circular cylinder of radius $R$ , length $L$	$M\frac{R^2}{2}$
Any diameter	Thin circular ring. Plane figure formed by two concentric circles of radius $R$ and $S$	$M\frac{R^2+S^2}{4}$
Polar axis	Spheroid of revolution, equatorial radius $R$	$M\frac{2R^2}{5}$

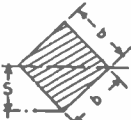
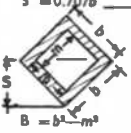
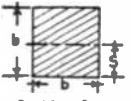
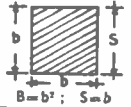
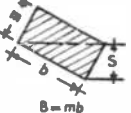
## MOMENTS OF INERTIA AND RADIUS OF GYRATION OF SOLID BODIES

Body	(Specific gravity of material = K) Moment of Inertia	Radius of gyration
 <p>Spherical shell</p> <p>Solid sphere</p> <p>Thick spherical shell inner radius = S</p>	$\text{Mass} \times \frac{2R^2}{3}$ $\frac{25 \cdot 12 R^2}{15} K$ $\frac{25 \cdot 12 (R^2 - S^2)}{15} K$	<p>.8165R</p> <p>.6324R</p> <p>.6324 <math>\sqrt{\frac{R^2 - S^2}{R^2 - S^2}}</math></p>
 <p>When R is small (thin rod)</p>	$\frac{3 \cdot 14 R^2 L (4L^2 + 3R^2)}{12} K$ $3 \cdot 14 R^2 L^3 K + 3$	$\sqrt{\frac{4L^2 + 3R^2}{12}}$ <p>.5775L</p>
 <p>Hollow cylinder, inner radius = S</p>	$3 \cdot 14 LR^2 K \div 2$ $\frac{3 \cdot 14 L (R^2 - S^2)}{2} K$	$\frac{R}{1 \cdot 414}$ $\sqrt{\frac{R^2 + S^2}{2}}$
 <p>When R is small (thin rod)</p>	$\frac{3 \cdot 14 R^2 L (L^2 + 3R^2)}{12} K$ $\frac{3 \cdot 14 R^2 L^3 K}{12}$	$\sqrt{\frac{L^2 + 3R^2}{12}}$ <p>.2887L</p>
 <p>About axis of cone</p> <p>About a diameter of base</p> <p>About an axis through vertex parallel to base</p>	$\frac{3 \cdot 14 R^4 H}{10} K$ $\frac{3 \cdot 14 R^2 H (2H^2 + 3R^2)}{60} K$ $\frac{3 \cdot 14 R^2 H (12H^2 + 3R^2)}{60} K$	<p>.548R</p> $\sqrt{\frac{2H^2 + 3R^2}{20}}$ $\sqrt{\frac{12H^2 + 3R^2}{20}}$
 <p>Perpendicular axis through centre</p> <p>Perpendicular axis in plane of one end</p>	$ABL \left( \frac{L^2 + B^2}{12} \right) K$ $ABL \left( \frac{4L^2 + B^2}{12} \right) K$	$\sqrt{\frac{L^2 + B^2}{12}}$ $\sqrt{\frac{4L^2 + B^2}{12}}$




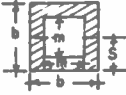
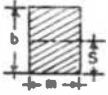
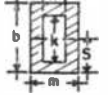
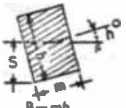
## MOMENTS OF INERTIA AND RADIUS OF GYRATION OF SOLID BODIES—continued.

Body	(Specific gravity of material = K) Moment of inertia	Radius of gyration
 <p>rad. S</p> <p>rad. R</p> <p>H</p> <p>About axis of conic frustum</p> <p>About a diameter of base</p>	$\frac{3 \cdot 14 H}{10} \left( \frac{R^3 - S^3}{R - S} \right) K$ $\frac{3 \cdot 14 H}{3} (R^2 + S^2 + RS) \times (RG)^2 K$	$.548 \sqrt{\frac{R^3 - S^3}{R^2 - S^2}}$ $RG = \sqrt{\frac{H^2 (R^2 + 3RS + 6S^2)}{10 (R^2 + RS + S^2)} + \frac{3}{20} \left( \frac{R^3 - S^3}{R^2 - S^2} \right)}$
 <p>Perpendicular axis in plane of large end</p>	$\frac{AL(D+B)(12L^2 + D^2 + B^2)}{48} K$	$.204 \sqrt{12L^2 + D^2 + B^2}$

## MOMENTS OF INERTIA, SECTION MODULI, ETC., OF SECTIONS

Section	Radius of gyration $v = \sqrt{\frac{P}{B}}$	Moment of inertia P	Section Modulus $T = \frac{P}{S}$
 <p>B = area</p> <p>S = distance from axis to extreme fibre</p> <p>B = <math>b^2</math></p> <p>S = 0.707b</p>	$= 0.289b$	$\frac{b^4}{12}$	$0.118b^2$
 <p>B = <math>b^2 - m^2</math></p> <p>S = 0.707b</p>	$= 0.289 \sqrt{b^2 + m^2}$	$\frac{b^4 - m^4}{12}$	$0.118 \frac{b^4 - m^4}{b}$
 <p>B = <math>b^2</math>; S = <math>\frac{1}{2}b</math></p>	$= 0.289b$	$\frac{b^4}{12}$	$\frac{b^2}{6}$
 <p>B = <math>b^2</math>; S = b</p>	$= 0.577b$	$\frac{b^4}{3}$	$\frac{b^2}{3}$
 <p>B = mb</p> <p>S = <math>\frac{mb}{\sqrt{m^2 + b^2}}</math></p>	$= 0.408 \frac{mb}{\sqrt{m^2 + b^2}}$	$\frac{m^2 b^3}{6 (m^2 + b^2)}$	$\frac{m^2 b^3}{6 \sqrt{m^2 + b^2}}$

## MOMENTS OF INERTIA, SECTION MODULI, ETC., OF SECTIONS—continued

Section B = area S = distance from axis to extreme fibre	Radius of gyration $v = \sqrt{\frac{P}{B}}$	Moment of inertia P	Section Modulus $T = \frac{P}{S}$
 <p><math>B = mb</math> <math>S = b</math></p>	$= 0.577b$	$\frac{mb^3}{3}$	$\frac{mb^2}{3}$
 <p><math>B = \frac{1}{2}mb</math> <math>S = \frac{2}{3}b</math></p>	0.236b	$\frac{mb^3}{36}$	$\frac{mb^2}{24}$
 <p><math>B = \frac{1}{2}mb</math> <math>S = b</math></p>	0.408b	$\frac{mb^3}{12}$	$\frac{mb^2}{12}$
 <p><math>B = b^2 - m^2</math>; <math>S = \frac{1}{2}b</math></p>	$0.289 \sqrt{b^2 + m^2}$	$\frac{b^4 - m^4}{12}$	$\frac{b^4 - m^4}{6b}$
 <p><math>B = bm</math> <math>S = \frac{1}{2}b</math></p>	0.289b	$\frac{mb^3}{12}$	$\frac{mb^2}{6}$
 <p><math>B = mb - hk</math> <math>S = \frac{1}{2}b</math></p>	$= 0.289 \sqrt{\frac{mb^2 - hk^2}{mb - hk}}$	$\frac{mb^3 - hk^3}{12}$	$\frac{mb^2 - hk^2}{6b}$
 <p><math>B = mb</math> <math>S = \frac{1}{2}(b \cos h + m \sin h)</math></p>	$.289 \sqrt{b^2 \cos^2 h + m^2 \sin^2 h}$	$\frac{mb}{12} (b^2 \cos^2 h + m^2 \sin^2 h)$	$\frac{mb}{6} \left( \frac{b^2 \cos^2 h + m^2 \sin^2 h}{b \cos h + m \sin h} \right)$

## HEAT

Heat involves an understanding of some of the basic laws of applied mechanics, chemistry and physics.

Force is a push or pull which tends to give motion to a body at rest. The unit of force is the pound.

Pressure is the pounds of force divided by the cross-sectional area over which the force is operating.

Work is the motion of the force through a certain distance, or, it is the product of pounds of force multiplied by distance, and is measured in foot-pounds, inch-pounds, foot-tons, etc.

Power is measure of work done during a certain time. It is measured in H.P. and one H.P. is equal to 33,000 ft.-lbs. of work per hour.

Energy represents the capacity to effect work. It can be either kinetic energy or potential. Potential energy is energy that is stored up, whereas kinetic energy is energy of movement. These energies can be changed one into the other. Energy may be in the form of either mechanical, radiant, kinetic, heat, or electrical energy.

The science of heat covers the study of the manner in which heat or heat energy can be altered into or from the other types of energy, and the physical and chemical laws which control this alteration.

The substance of which the material world is composed is called *matter*, which is anything having weight and occupying space. Matter consists of very minute particles known as molecules. These molecules are separated from each other by distances which are extremely large in ratio to the size of the molecule. Molecules are vibrating constantly and this constant vibration results in heat being produced.

There are three types of matter, solid, gaseous and liquid. All matter can exist in any one of these three states, depending on its pressure, volume and temperature. The change between each of the three states of matter is due to the amount of molecular motion of vibration and the mutual attraction of one molecule to another.

Temperature is the amount of vibration of an individual molecule, or the amount of the heat intensity. It is not the same as heat or heat energy. For instance, a jug of water may be at a certain temperature and hold a certain amount of heat energy. If one-third of the water is thrown away, the remaining part will still have the same temperature, but will contain only two-thirds of the heat energy.

A thermometer is used for temperature measurement. The most simple type of thermometer is a glass tube from which the air has been exhausted and the top end sealed, while the lower end is expanded into a bulb filled with a suitable liquid normally mercury. As the bulb is heated the liquid expands and rises in the tube, and if cooled the liquid contracts and drops in the tube. A scale with graduated divisions is marked either on the tube or on a flat surface near to the tube.

The most commonly used scales are the Fahrenheit and the Centigrade. The Fahrenheit scale is in general use normally and the Centigrade is used for scientific work.

Absolute temperature means the temperature above absolute zero degrees. By absolute zero is meant the temperature at which all molecular motion or vibration would cease. The following table gives the temperature at which some important phenomena occur on the two scales of temperature :—

	Centigrade	Fahrenheit.
Absolute zero	—273.1°	—459.6°
Water freezes	0°	32°
Water boils	100°	212°

## TEMPERATURE CONVERSION FACTORS

F = Fahrenheit. R = Reamur. C = Centigrade.

$$^{\circ}\text{F} = \frac{9^{\circ}\text{C} + 32}{5}$$

$$^{\circ}\text{R} = \frac{4^{\circ}\text{C}}{5}$$

$$^{\circ}\text{C} = \frac{5^{\circ}\text{R}}{4}$$

$$^{\circ}\text{F} = \frac{9^{\circ}\text{R} + 32}{4}$$

$$^{\circ}\text{R} = \frac{4^{\circ}(\text{F}-32)}{9}$$

$$^{\circ}\text{C} = \frac{5^{\circ}(\text{F}-32)}{9}$$

A *pyrometer* is any thermometer which checks high temperatures, such as in electric furnaces and crucibles. Pyrometers are also used to measure boiler steam temperatures. They are of various types—pressure, expansion, electric, etc.

*Standard thermometer.*—The high temperature scale is decided by nitrogen gas expansion in the constant-volume gas thermometer. This instrument is not used commercially, but as a standard. By its use a series of fixed data points have been set which control the scale of commercial thermometers and pyrometers.

*Thermometric scales.*—In the Fahrenheit scale, the space between freezing and boiling points of water is divided in 180 units, called degrees. The boiling point is 212 and the freezing point 32, while zero is a point which, at the time this thermometer was invented, was incorrectly reckoned to be the lowest obtainable. In both the Centigrade and Reamur system the fixed space between the freezing and boiling points is divided respectively into 100 and 80 equal units or degrees. In both these, the freezing point is set at zero.

*Thermometry divisions.*—Due to changes in the temperatures to be checked, and in the characteristics of bodies whose temperatures are desired, and due to limitations in the different measuring instrument, thermometry is subdivided into two parts. The thermometer utilises the entry of the measuring instrument into the body or substance whose temperature is required and gets the results through heat conduction. In the second, pyrometers functioning by radiation are used, at a distance from the substance or body whose temperature is wanted. Radiation methods depend on the fact that all bodies radiate heat energy and the quantity radiated alters with the temperature and the nature of the body. This energy can be measured.

Below the boiling point, the hydrogen gas thermometer is the virtual standard with which mercury thermometers are controlled, but over this point the nitrogen gas thermometer is utilised as a standard. In both of these the alteration in temperature is calculated by the alteration in pressure of a constant volume of gas.

**Correction of stem for thermometers.**—Most thermometers are graduated to read for complete immersion with the bulb and stem at the one temperature, and should be checked like this when compared against a standard thermometer. If the stem emerges into a space either hotter or colder than the bulb, a "stem correction" must be used with the observed temperature apart from any correction that may be needed in comparison with the standard.

**Formula for the stem correction:**  $0.000085 \times L (p-K)$ , in which  $p$  is the observed temperature,  $K$  is the mean temperature of the uncovered part of the stem, and  $L$  is the number of degrees of uncovered stem; while  $0.000085$  is the difference between coefficient of expansion of mercury and of the glass stem.

**Annealing thermometers.** Every thermometer should be correctly annealed prior to use. Should this not have been done, the true melting point and also the "fundamental space" (the space between the melting and boiling points) may alter greatly. After much use at a higher temperature the melting point will also alter, so that for accurate work a thermometer must be recalibrated occasionally.

**Absolute zero.**—Tests show that at 32°F a perfect gas of constant pressure expands 1/491.6 part of its volume for 1° Fahrenheit increase in temperature, e.g., if a specific volume of gas at 45°F. occupies 500 cu. ft. at a temperature of 46° F., its volume becomes 500 plus 500/491.6 which equals 501.015 cu. ft.

**The absolute scale.** To make easy the use of this law a thermometric scale is utilised in which the point equal to -460°F. is used as zero point on this scale. The degrees are identical to those of the standard Fahrenheit scale. Temperatures referred to by this scale are named absolute temperatures. To change any reading on a Fahrenheit thermometer in terms of absolute temperature, add 460 to thermometer reading. Thus, 65° on the Fahrenheit scale, becomes on the absolute temperature scale 525°. On the Centigrade scale, absolute zero is -273.1° below zero.

**Heat energy source.**—Nearly all of the earth's heat comes from the sun; e.g., water from the sea, lakes and streams is evaporated by the sun's heat rays and forms clouds. The clouds condense and drop to the earth as rain. The water which falls on the earth's higher regions is available as potential energy, which can be changed into electrical or mechanical energy. Mechanical or electrical energy can be changed into heat energy, e.g., the mechanical energy of friction resulting from rubbing two sticks together can cause the freeing of heat due to the combustion of the sticks; or a piece of metal may be bent repeatedly and caused to get hot. Electrical energy is changed into heat energy when a wire passes electricity as in the case of electric fires, etc. Kinetic energy is changed and freed as heat energy in many chemical reactions, as when the burning of coal, wood, oil or gas takes place. These alterations of form of energy into a different type prove the **FIRST LAW OF THERMODYNAMICS**, which is that "Energy cannot be created or destroyed, but can be altered from type into a different type."

Examination of any heat engine using superheated steam, for example, will prove that the steam is exhausted without using all of the heat which was supplied; if this was not so the engine itself would not be hot and all the steam would be converted to power. Science proves that it is impossible to invent any machine which will constantly alter all of the heat energy fed to it into mechanical form, but that it will reject a part of the heat fed to it at a lower temperature than that at which it was received. This proves the **SECOND LAW OF THERMODYNAMICS**, which says "Heat cannot be made to flow of its own accord from a lower to a higher temperature."

**Efficiency formula.**—Thermodynamic laws are the basis for the formula which is utilised in finding the efficiency factor of heat engines. It says the efficiency of a heat engine is equal to the heat added, less the heat lost, divided by the heat added. This may be expressed as  $K$  equals  $(P_1 - P_2)$  divided by  $P_1$ , where  $K$  equals efficiency,  $P_1$  the heat added and  $P_2$  the heat lost.

The quantity of heat held in any matter depends on its weight, nature, state (liquid, solid or gaseous), temperature and, if in a gaseous state, the pressure of the matter.

The unit measure of heat quantity is the **BRITISH THERMAL UNIT (B.Th.U.)**. The value of a B.Th.U. is the quantity of heat needed to raise the temperature of one pound of water through one degree Fahrenheit. For scientific work, the small and large calorie is used. The **SMALL CALORIE** is the quantity of heat needed to raise the temperature of one gram of water through one degree Centigrade. The **LARGE CALORIE** is equal to 1,000 small calories.

As mechanical energy is changeable into heat energy, there is relationship between the units of mechanical and heat energy. This is as follows:—

1 H.P.	equals	42.42 B.Th.U./min.
1 H.P.	..	2545 B.Th.U./hr.
1 B.Th.U.	..	778 ft.-lbs.
1 ft.-lb.	..	0.00128 B.Th.U.

All kinds of matter need a certain amount of heat which must be added to the substance so as to increase its temperature one degree. The amount of B.Th.U.s. that are to be added to each pound of matter to raise its temperature one degree is known as the specific heat factor. The specific heat factor alters with the temperature and as all matter varies in volume or pressure with temperature changes, in calculating, always distinguish between specific heat at a constant volume and at a constant pressure. As solids and liquids do not vary much in volume because of temperature or pressure changes, the specific heat of these substances is practically constant.

**Mean specific heat.**—With specific heat at constant volume and specific heat at constant pressure, it is necessary to distinguish between mean specific heat and instantaneous specific heat. The mean specific heat of a body, over a set temperature change, is the quantity by which such range must be multiplied to find the quantity of heat needed to raise unit weight of the substance through the said temperature range, under the state of volume or pressure standards which exist for that particular case. In all calculations dealing with steam turbines, steam boilers and steam engines, mean specific heat is utilized. If a pound of water is the substance under consideration, its mean specific heat over a temperature range of 32 to 212°F., at standard atmospheric pressure, is one B.Th.U. The pound is the unit of weight used in noting the specific heat of all substances.



**Thermal capacity** of a substance is the amount of heat needed to raise the temperature of unit weight of the substance through one degree. It is sometimes known as heat capacity.

The amount of heat needed to alter the temperature of a substance is:  $ABP(F_2 - F_1)$  in which B is the specific heat of the substance, A is the total heat added to the substance in B.Th.U.,  $F_2$  and  $F_1$  are the final and initial temperatures respectively and P is the weight in pounds.

This formula is incorrect if a change of condition takes place, such as if the temperature limits of the change include either the melting or boiling point of the substance.

**To check specific heat.**—The specific heat is usually arrived at by mixing one substance, whose specific heat is known, with another substance whose specific heat is unknown, in an instrument called a CALORIMETER. The substance is heated and mixed with the other cold substance. The temperatures previous to and after mixing are noted. The unknown specific heat is then worked out by the following formula (here the hot substance is the one whose specific heat is unknown):—

$$S = TM(A - C) - K(B - A)$$

S and T are the specific heats for the hot and cold substances, respectively K and M the weight in pounds of the hot and cold substances and A, B and C the temperature in degrees. F. of the mixture, the hot and the cold substance, respectively.

Heat is moved in three ways—by convection, by conduction and by radiation. CONVECTION is affected by causing in gas or liquid, currents to move from the hotter to the colder parts of the fluid. These currents are movements of groups of molecules and not the movement of individual molecules in conduction. CONDUCTION is affected by increasing the molecular vibration at one point in the substance where heat is applied. This increase in vibration then moves from one molecule to the next throughout the whole of the substance. RADIATION is affected by causing wave motion which carries the heat from a hotter to a colder substance when they are not actually in contact with one another.

Heat transfer by conduction is calculated thus:—

$$A = (MB(F_2 - F_1)h) \div P$$

where M is the thermal conductivity, A is the total heat transferred,  $F_2$  and  $F_1$  are the final and initial temperatures in degrees F., h is the time in hours, and P is the thickness in inches.

Thermal conductivity is the heat transferred by a substance in B.Th.U. per hour per square inch of area per inch of thickness.

Heat transfer by convection cannot be given in a simple formula, as for conduction. The transfer increases with temperature and temperature difference, and is higher with the less viscous fluids (i.e., fluids which flow easily).

Heat transfer by radiation is calculated by the Stefan-Boltzman formula:—

where M is a constant depending on the material, and  $F_1$  and  $F_2$  are the absolute temperatures in ° F. of the hot and cold bodies, respectively. This formula reckons that the cold body is situated so as to receive all of the heat radiated by the hotter body. Values of M are given in the Table following:

$$A = M(F_2^4 \div 100) - (F_1^4 \div 100) \text{ in B.Th.U. per hour per sq. ft.}$$

In most cases of heat transfer, all three types of transfer are involved.

Material Values of M for Transfer of Heat by Radiation:—

Material	M	Material	M	Material	M
Perfect Black ... ..	.162	Ice ... ..	.109	Glass ... ..	.152
Dull Iron ... ..	.152	Earth ... ..	.059	Aluminium ... ..	.506
Zinc ... ..	.032	Lime Plaster ... ..	.149	Slate ... ..	.113
Water ... ..	.109	Copper ... ..	.028	Incandescent Body ... ..	.154

Heat added to or taken from a substance can cause a physical or chemical change. A physical change can be a change in temperature, change in volume, change in state, absorption or solution. The physical change may be either reversible or irreversible, subject to whether after the change is made the original condition of the substance can be restored.

Expansion and contraction are physical changes that take place when temperature is raised or lowered. The quantity of expansion or contraction is measured by the coefficient of expansion, which is unit change in length per unit length of the substance per degree alteration in temperature.

If heat is added to a substance it is accompanied by an increase in temperature, an alteration in the substance's internal structure, and the displacement of surrounding substances.

The temperature rise increases individual molecule movement and increases the substance's heat energy, its SENSIBLE HEAT. The alteration in internal structure is a change in the molecular arrangement and attraction, and sometimes is accompanied by an alteration of state. The heat energy causing this alteration of internal structure is known as INTERNAL LATENT HEAT.

The result of altering the sensible heat and internal latent heat is to alter the dimensions of the substance and produce displacement of the surrounding media against resistance. The heat energy needed to effect this change is EXTERNAL LATENT HEAT.

A substance's total heat is the sum of the sensible, internal latent and external latent heat. As it is impossible to reckon the actual total heat of a substance, the total heat above 32°F. is the quantity normally utilised in comparing various substances.

To make this clear, examine the effect of heating water from ice to boiling point, where it becomes steam.

The heat added to raise the temperature of water from ice to boiling point increases its heat energy, but causes no change in the molecular structure. This is the SENSIBLE HEAT.

When heat is then added to the water at boiling point and at atmospheric pressure, the water does not get hotter but evaporates into steam. This quantity of heat is the internal latent heat, or the INTERNAL LATENT HEAT OF VAPORISATION.

This heat is not permanently lost because it reappears when the substance goes from a gaseous to a liquid state, or from a liquid to a solid state. In the case of water frozen into ice, the heat held in the water, over freezing point, is released into the air in the process of freezing. Also, the heat contained in steam is released to the air when steam condenses into water.

The EXTERNAL LATENT HEAT OF VAPORISATION is heat added at boiling point which does not cause a change in temperature, but which is used in overcoming external resistance so as to increase the volume as the water changes into steam. When evaporating one gallon of water at 212° into steam at 212° 8,976 B.Th.U. are used up as internal latent heat and 727 B.Th.U. as external latent heat. The total being 9,703 B.Th.U., which is the total latent heat of vaporisation.

Therefore, the TOTAL HEAT required to raise water from freezing point to boiling point and entirely evaporate it is the sum of the sensible, internal latent and external latent heats.

*Latent heat of fusion.*—If heat is added to ice at freezing temperature, the ice will melt, but its temperature does not rise. The heat thus added in altering the state of the ice is latent heat, and in this case is known as latent heat of fusion.

The heat combustion of a fuel, etc., is the quantity of B.Th.U. which is generated by the combustion of one pound of the fuel, or, using the metric system, the number of calories generated by the combustion of one gram of the fuel. The quantity of heat units is a constant for any given fuel, no matter how combustion takes place, subject to it being complete, and is known as the calorific content of the fuel.

*Avogadro's law.*—Equal volumes of different gases at the same temperature and pressure have the same number of molecules.

*Boyle's law for gases.*—The volume of a given quantity of any gas varies inversely as the pressure which is applied to it when it is maintained at a constant temperature.

For a perfect gas, changing from pressure A and volume B to pressure C and D without alteration of temperature the following equation is true :—

$$AB = CD$$

*Gay-Lussac's or Charles' law of gases.*—At constant volume the pressure of a given quantity of any gas increases about 1/273 of the pressure at 0°C. for each rise of 1°C. in temperature and at a constant pressure, the volume of a given quantity of any gas increases about 1/273 of its volume at 0°C for each rise of 1°C.

*Thermal conductivity* is the time rate of transfer of heat by conduction, through unit thickness and across unit area for a unit difference of temperature. It is reckoned as calories per square centimetre for a thickness of one centimetre per second for a difference of temperature of 1°C.

If the two opposing faces of a cube of a material are held at temperatures E and F, the heat conducted across the cube section A and thickness P in a time T will be equal to :—

$$V \frac{(F-E) AT}{P} \text{ calories.}$$

V is a constant which depends on the nature of the material called the specific heat conductivity. V is usually given for calories with E and F in °C, A in cm<sup>2</sup>, T in sec. and P in cm.

### THERMAL CONDUCTIVITY

Metals	Conductivity	Metals	Conductivity	Metals	Conductivity
Copper ...	1.000	Gold ...	.710	Constantan ...	.052
Silver ...	.974	Lead ...	.083	Brass ...	.202
Palladium ...	.168	Iron ...	.162	Antimony ...	.043
Platinum ...	.166	Molybdenum ...	.345	Aluminium ...	.501
Rhodium ...	.211	Magnesium ...	.373	Bismuth ...	.019
Zinc ...	.265	Steel ...	.114	Cadmium ...	.221
Nickel ...	.143	Iridium ...	.139	Mercury ...	.016
Solids	Conductivity	Liquids	Conductivity	Gases	Conductivity
Carbon ...	.011	Benzole ...	.0003	Air ...	.00006
Glass ...	.002	Ether ...	.0003	Argon ...	.00004
Lime ...	.0003	Glycerine ...	.0006	Ammonia ...	.00005
Marble ...	.007	Olive Oil ...	.0004	Carbon Dioxide ...	.00004
Brick ...	.0017	Turpentine ...	.0003	Hydrogen ...	.00003
Wood ...	.0001	Chloroform ...	.0002	Nitrogen ...	.00005
Snow ...	.0005	Water ...	.0013	Oxygen ...	.00006

*Petit's and Dulong law of thermal capacity.*—For simple materials the atoms all have practically the identical thermal capacity.

The product of the specific heat by the atomic weight is a constant equal to approximately 6.39.

*Thermal expansion.*—The coefficient of linear expansion is the proportion of the alteration in length per degree to the length at 0°C. The coefficient of surface expansion is twice the linear coefficient. The coefficient of volume expansion is thrice the linear coefficient for solids. The coefficient of volume expansion for liquids is the proportion of the alteration in volume per degree to the volume at 0°C. The value of the coefficient varies with temperature. The coefficient of volume expansion for a gas held at constant pressure is practically identical for all gases and temperatures and is equivalent to 1 ÷ 273 or .00367 for 1°C. change in temperature.

If A is the length at 0°C. B the coefficient of linear expansion, then the length at M is equal to :—

$$A (1 + BM)$$

## COEFFICIENTS OF THERMAL EXPANSION

Metal	Linear Coefficient × 10 <sup>-6</sup> per °C.	Metal	Linear Coefficient × 10 <sup>-6</sup> per °C.	Metal	Linear Coefficient × 10 <sup>-6</sup> per °C.
Aluminium ...	23.15	Indium ...	42.36	Rhodium ...	8.46
Antimony ...	10.88	Iron ...	9.16	Rubidium ..	86.55
Beryllium ...	12.41	Lead ...	28.63	Silver ...	18.65
Bismuth ...	13.43	Magnesium	26.21	Sodium ...	63.24
Brass ...	18.93	Mercury ...	43.54	Steel ...	11.21
Bronze ...	17.42	Molybdenum	4.94	Thorium ...	12.22
Cadmium ...	29.34	Monel ...	14.99	Tin ...	26.95
Cobalt ...	12.36	Nickel ...	12.76	Tungsten ...	4.22
Copper ...	16.81	Osmium ...	6.57	Zinc ...	26.56
Gold ...	14.32	Palladium ...	11.75		
Gun Metal ...	18.31	Platinum ...	8.99		

Solids	Cubical Coefficient × 10 <sup>-6</sup> per °C.	Solids	Cubical Coefficient × 10 <sup>-6</sup> per °C.	Solids	Cubical Coefficient × 10 <sup>-6</sup> per °C.
Antimony ...	3.16	Glass ...	2.48	Quartz ...	3.52
Asphalt ...	58.00	Ice ...	11.25	Silver ...	5.82
Beryl ...	3.17	Iron ..	3.56	Slate ...	2.25
Bismuth ...	4.02	Marble ...	4.50	Sulphur ...	22.34
Diamond ...	.38	Paraffin ...	58.84	Tar ...	67.50
Fibre ...	2.74	Platinum ...	2.65	Tin ...	6.88
Galena ...	5.56	Porcelain ...	1.12	Zinc... ..	8.93

Gases	Volume Coefficient × 10 <sup>-6</sup> for constant pressure per °C.	Gases	Volume Coefficient × 10 <sup>-6</sup> for constant pressure per °C.	Gases	Volume Coefficient × 10 <sup>-6</sup> for constant pressure per °C.
Acetylene ...	3.77	Carbon Dioxide	3.74	Oxygen ...	4.87
Air ...	3.67	Chlorine ...	3.85	Sulphur Dioxide	3.91
Ammonia ...	3.86	Hydrogen ...	3.66	Water vapour	4.06
		Nitrogen ...	3.67		

Liquids	Cubical Coefficient × 10 <sup>-4</sup> per °C.	Liquids	Cubical Coefficient × 10 <sup>-4</sup> per °C.
Alcohol ...	12.3	Glycerine ...	5.3
Benzine ...	12.4	Oil Olive ...	7.3
Chloroform	12.8	Turpentine...	9.5
		Water 20°—40°C.	3.5

## THERMODYNAMIC LAWS

No heat can be transferred from a colder to a hotter body by any continuous self-sustaining process. When mechanical work is changed into heat or vice versa the quantity of work is, in every case, equal to the amount of heat.

Van der Waal's variation of Boyle's law.

$$\left(A + \frac{C}{B^2}\right)(B - D) = MN.$$

where A and B are the pressure and volume at any constant temperature and C and D are constants. M is the gas constant and N the absolute temperature.

Latent heat of fusion.—The amount of heat needed to alter one gram of a solid into a liquid without any temperature alteration.

Heat quantity is reckoned by the alteration of temperature produced. The measure unit of heat is the CALORIE which is the amount of heat needed to alter the temperature of one gram of water from 3.5°C. and is called the small calorie. Should the temperature change involved be from 14.5 to 15.5°C., the measure unit is known as the normal calorie. The average calorie is .01 the amount of heat needed to raise the temperature of a gram of water from 0°C to 100°C. The large calorie is equivalent to 1,000 small calories. the British thermal unit is the heat needed to raise the temperature of one pound of water through 1° F. at its maximum density, and is equal to 252 calories.

**Loschmidt's number.**—The amount of molecules per unit volume of an ideal gas at a temperature of 0°C. and held at normal atmospheric pressure. ( $n_0 = 2.705 \times 10^{19}$  per  $\text{cm}^3$ ), this is equivalent to  $2705 \times 10^{16}$  molecules per cubic centimetre.

**Specific heat of a substance** is the proportion of its thermal capacity as compared to that of water at 15°C.

If B calories are needed to raise the temperature of M grams of a material from E to F °C., then the specific heat, or thermal capacity of the substance, is equal to :—

$$B \div M (F - E)$$

**To find specific heat by use of the Bunsen's ice calorimeter.**—A substance of mass M and at a temperature A causes a movement of the mercury column of B centimetres length in a tube whose volume per unit length is V. The specific heat is then equal to :—

$$\frac{884 VB}{MA}$$

**To find specific heat by use of the Black's ice calorimeter.**—If a substance of mass M, at a temperature A, melts a mass F of ice, its temperature being reduced to 0°C., the specific heat of the substance is then equal to :—

$$80.1 F \div MA$$

**To find specific heat by method of mixtures.**—Where a mass M of the material is raised to a temperature of A, then put in a mass of water N at a temperature B contained in a calorimeter with a mixer of the same substance as the calorimeter of mass F. The specific heat of the calorimeter is V, the final temperature being K. The following formula then holds good where T is the specific heat of the test piece :—

$$(FV + N) (K - B) = MT (A - K)$$

### LATENT HEAT AND BOILING POINT OF LIQUIDS AT SEA LEVEL

Substance	Latent Heat B.Th.U. per lb.	Boiling Point
Air ... ..	100 approx.	—313°F.
Water ... ..	960 ..	212°F.
Mercury ... ..	110 ..	674°F.
Carbonic Acid ... ..	95 ..	—108°F.
Ammonia ... ..	550 ..	—29°F.

### HEAT OF COMBUSTION OF SUBSTANCES

Name	B.Th.U.s. per lb.	Name	B.Th.U.s. per lb.
Soft Wood ... ..	9,092	Petroleum ... ..	18,763
Hard Wood ... ..	8,633	Olive Oil... ..	16,958
Peat Wood ... ..	10,697	Cotton Oil ... ..	17,033
Asphalt ... ..	17,843	Napthalin ... ..	16,873
Pitch ... ..	15,088	Sperm Oil ... ..	18,422
Sulphur ... ..	4,495	Tallow ... ..	16,951
Paraffin ... ..	19,876	Coal Gas Oil ... ..	15,930

### SPECIFIC HEAT AND DENSITY OF GASES

Name	Specific Heat at constant volume	Specific Heat at constant pressure	Cubic feet per lb. at atmos. pressure and 60°F
Air ... ..	0.1682	0.2373	13.02
Ammonia ... ..	0.3714	0.5082	22.14
Carbonic Acid ... ..	0.1723	0.2168	8.53
Helium ... ..	0.7669	1.2503	94.11
Hydrogen ... ..	2.4112	3.4092	188.14
Nitrogen ... ..	0.1724	0.2436	13.42
Oxygen ... ..	0.1561	0.2174	11.71
Sulphur Dioxide ... ..	0.1238	0.1543	5.83
Steam ... ..	0.3706	0.4806	21.05

### HEAT COLOUR TEMPERATURES

Colour	°C	°F	Colour	°C	°F
Just visible red ... ..	500-600	932-1112	Orange ... ..	950-1000	1750-1835
Dull cherry red ... ..	700-750	1300-1385	Light Orange ... ..	1000-1050	1835-1925
Cherry red ... ..	750-825	1385-1517	Lemon ... ..	1100-1200	2012-2200
Bright cherry red ... ..	825-875	1517-1600	White ... ..	1200-1300	2200-2372
Brightest red ... ..	900-950	1652-1750			

## ELECTRICAL CURRENT HEATING EFFECTS

The heating effect of an electric current varies as (1) The square of the voltage applied or (2) as the square of the current applied.

Heating constants.—1 kilowatt hour = 3,415 British Thermal Units. 1 cubic foot of coal gas = 450 B.Th.U s. 1 lb. gasoline or petrol = 17,700 B.Th.U s. and 1 lb. of steam coal = 14,000 B.Th.U s approximately.

180 B.Th.U s. are required to raise 1 lb. of water from freezing to boiling point and 225 B.Th.U s. are required for 1 pint of water.

## LAWS OF GAS

Heat engines usually use an expanding gas for changing the heat energy into mechanical work. So as to give the condition of a gas, the volume, pressure, density, temperature and type of gas must be known. The laws controlling the condition of a gas can be for a perfect or an actual gas. Normally, the better the conditions of the gas are from the liquid state the more nearly the gas follows the perfect laws.

The perfect gas will follow BOYLE & CHARLES' laws which say by formula that  $BM = KSL$ , in which B is the pressure, M the volume, K the weight in pounds, S the gas constant depending on the particular gas used, and L the absolute temperature.

This formula shows that there are three inter-related variables which define a gas's condition and that by knowing any two of these variables the third may be calculated.

If the volume of gas is increased it is said to expand, and if the volume decreases the gas is compressed. There are four normal ways of changing the volume. (1) The volume can be constant and the adding of heat means an increase in pressure and temperature, as takes place when heating water in a closed vessel. (2) The volume can be altered by increasing the temperature and maintaining the pressure constant, as by heating steam in a cylinder with a weighted piston free to move, set on top of the gas. (3) Adiabatic expansion. This form of expansion is more akin to the conditions in the steam turbine and steam engine than any of the other ways. In adiabatic expansion there is no increase of heat or loss of heat, except for the amount of heat energy which is utilised in doing work; e.g., imagine the steam in the cylinder of an engine expanding behind the piston without any condensation leakage or other losses. The only heat energy used is that needed to effect the work necessary to move the piston. (4) The pressure and volume of the gas may be altered and the temperature maintained constant. This is not possible except by mathematics.

## EXPANSION OF GASES

Charles' law or Gay-Lussac's law.—The volume of a gas increases in ratio to the absolute temperature. If A and B are volumes of the same mass of gas at absolute temperatures C and D, then :—

$$\frac{A}{B} = \frac{C}{D}$$

For an original volume E at 0°C the volume at W°C maintained at constant pressure is equal to :—

$$E \left( 1 + \frac{.00367 W}{273} \right)$$

General law for gases is expressed thus :—

$$CD = AB \left( 1 + \frac{W}{273} \right)$$

where A, B, C, D denote the pressure and volume at 0° and W °C.

The law can also be shown as :—

$$\text{pressure volume is equal to } \frac{SM}{T}$$

where M is the mass of gas at absolute temperature T. S is the value of the constant which is dependent upon the units used. Boltzmann's molecular gas constant is got by reckoning M in terms of the number of molecules.

For volume in cubic centimetres, pressure in dynes per square centimetre and temperature in °C on the absolute scale S is equal to :—

$$83136 \times 10^6$$

To get the reduction of a volume of gas at 0°C and 760 mm. pressure. K is the original volume of the gas at temperature W and pressure P the volume at 0°C and 760 mm. pressure will be equal to :—

$$\frac{K}{\left( 1 + \frac{W}{273} \right)} \times \frac{P}{760}$$

If D is the original density the density at 0°C and 760 mm. pressure will be equal to :—

$$D \left( 1 + \frac{W}{273} \right) \frac{760}{P}$$

Dalton's law of partial pressures.—The pressure effected by a mixture of gases is equal to the sum of the separate pressures which each gas would effect if it solely filled the whole available volume. This law is denoted by the following formula where A is the pressure of a mixture of gases filling volume space M and B, C, D and E, etc., are the separate gases filling this volume individually :—

$$AM = M(B + C + D + E, \text{ etc.})$$

Critical temperature is the temperature over which a gas cannot be liquified by pressure only. Critical pressure is that pressure under which a substance may exist as a gas in balance with the liquid at the critical temperature.

Dew point is the temperature at which water vapour condensation in the air results.

Isothermal.—If a gas passes through a number of pressure and volume changes without alteration of temperature the variations are known as isothermal.

Vaporisation.—Latent heat is the amount of heat needed to alter one gram of liquid into vapour without variation of temperature.

## SOUND

Wien's displacement law.—If the temperature of a radiating black body rises, the wave length equal to maximum energy drops in such a manner that the product of the absolute temperature and wave length is always constant.

Lissajou's figures is the line described by a particle which is simultaneously displaced by two simple harmonic movements at right angles, when the periods of the two motions are in the proportion of two small whole numbers and it displays a number of identifying curves called Lissajou's figures.

Frequency of vibrating strings.—The fundamental frequency of a stretched string is equal to :—

$$\frac{1}{2V} \sqrt{\frac{A}{D}}$$

where V is the length ; A the tension and D the mass per unit length.

## VIBRATIONS AND THE MUSICAL SCALE

Vibrations per sec.	Note on Musical Scale.	Vibrations per sec.	Note on Musical Scale.
26.66 ...	A	512 ...	C
30 ...	B	576 ...	D
32 ...	C	640 ...	E
36 ...	D	682.66 ...	F
40 ...	E	768 ...	G
42.66 ...	F	853.33 ...	A
48 ...	G	960 ...	B
53.33 ...	A	1,024 ...	C
60 ...	B	1,152 ...	D
64 ...	C	1,280 ...	E
72 ...	D	1,365.33 ...	F
80 ...	E	1,536 ...	G
85.33 ...	F	1,706.66 ...	A
96 ...	G	1,920 ...	B
106.66 ...	A	2,048 ...	C
120 ...	B	2,304 ...	D
128 ...	C	2,560 ...	E
144 ...	D	2,730.66 ...	F
160 ...	E	3,072 ...	G
170.66 ...	F	3,413.33 ...	A
192 ...	G	3,840 ...	B
213.33 ...	A	4,096 ...	C
240 ...	B	4,608 ...	D
256 ...	Middle C	5,120 ...	E
288 ...	D	5,461.33 ...	F
320 ...	E	6,144 ...	G
341.33 ...	F	6,826.66 ...	A
384 ...	G	7,680 ...	B
426.66 ...	A	8,192 ...	C
480 ...	B	9,216 ...	D

Ratio of vibrations of 1 octave in any part of the Musical Scale :—

NOTE ...	C.	D.	E.	F.	G.	A.	B.	C.
RATIO ...	1	9/8	5/4	4/3	3/2	5/3	15/8	2
DECIMAL RATIO ...	1	1.125	1.25	1.33	1.5	1.66	1.875	2
TONIC SOL FA SCALE ...	Doh	Ray	Me	Fah	Soh	Lah	Te	Doh

For a string of circular section of length V, tension A, density D and radius R, the frequency of the fundamental is equal to :—

$$\frac{1}{2VR} \sqrt{\frac{A}{3.1416D}}$$

The frequency in vibrations per second will be given if A is in dynes, R and V in cm and D in grams per cubic centimetre.

*Intensity of sound* is dependent on the energy of the wave movement. The intensity is calculated by the energy in ergs transmitted each second through one square centimetre of surface.

The energy in ergs per cubic centimetre in a sound wave is equal to :—

$$19.74 (DFA^2)$$

where D is density in grams per cubic centimetre, F is frequency in vibrations per second and A is amplitude in cm. The energy arriving at the ear in unit time is also proportional to the velocity of transmission.

**Beats.**—Two tones of slightly different frequencies sounded at the same time interfere so as to generate a sound of regularly varying intensity. The number of beats per second is the difference in frequency of the two tones.

**Organ pipes.**—The vibration frequency of a closed pipe or any other column of air of length V, where S is the velocity of sound in air, for the fundamental and the first four overtones respectively is equal to :—

$$\frac{S}{4V}, \frac{3S}{4V}, \frac{5S}{4V}, \frac{7S}{4V}, \frac{9S}{4V}$$

For an open organ pipe the vibrations are equal to :—

$$\frac{S}{2V}, \frac{2S}{2V}, \frac{3S}{2V}, \frac{4S}{2V}, \frac{5S}{2V}$$

**Speed of a compressional wave**, in an elastic medium, in terms of elasticity M (bulk modulus) and density D, is equal to :—

$$\sqrt{\frac{M}{D}}$$

The speed of sound in air, where K is the pressure and D the density is equal to :—

$$\sqrt{\frac{K}{D}} \cdot 1.4$$

**Speed of a wave.**—The speed of transmission in terms of wave length W and period V or frequency F is equal to :—

$$FW \text{ or } \frac{W}{V}$$

*Pitch of sound* is set by the number of vibrations per second.

*Stationary or standing waves* result from the simultaneous transmission in a medium of two similar wave motions in opposite directions. Fixed points of lowest amplitude are called nodes. A loop or antinode is the point of greatest amplitude between two nodes. A segment extends from one node to the next.

**Speed of a transverse wave** in a stretched cord is equal to :—

$$\sqrt{\frac{A}{M}}$$

where A is the tension of the cord in dynes and M the mass per unit length

*Quality or timbre of sound* is dependent upon the coexistence with the fundamental of other vibrations of various frequencies and amplitudes.

**Velocity of water waves.**—If the depth H is minute compared with the wave length, the speed is equal to :—

$$\sqrt{32.174H}$$

In deep water for a wave length W the speed is equal to :—

$$\sqrt{\frac{32.174W}{6.28}}$$

If the wave length is less than about 1.5 cm., the speed increases as the wave length decreases and is equal to the following equation :—

$$\text{speed} = \sqrt{\frac{6.28D}{WS} + \frac{32.174W}{6.28}}$$

where D is the surface tension and S the density of the liquid. The speed will be given in cm. per sec. if H, and W are in cm., gravity in cm. per sec.<sup>2</sup>, and D in dynes per cm. and S in grams per cm.<sup>3</sup>.

## ELECTRICITY AND MAGNETISM

Ohm's Law.

$$\begin{aligned} \text{Watts} &= (\text{Amperes})^2 \times \text{Resistance} \\ &= (\text{Volts})^2 \div \text{Resistance} \\ &= \text{Amperes} \times \text{Volts} \\ \text{Resistance} &= \text{Volts} \div \text{Amperes} \\ &= (\text{Volts})^2 \div \text{Watts} \\ &= \text{Watts} \div (\text{Amperes})^2 \end{aligned}$$

Resistance in series.

$$R = R_1 + R_2 + R_3 + \dots$$

Resistances in parallel.

$$R = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots}$$

Resistances in series-parallel.

$$R = \frac{1}{\frac{1}{R_1 + R_2} + \frac{1}{R_3 + R_4} + \frac{1}{R_5 + R_6} + \dots}$$

Inductances in parallel.

$$L = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \dots}$$

$$\begin{aligned} \text{Amperes} &= \text{Volts} \div \text{Resistance} \\ &= \text{Watts} \div \text{Volts} \\ &= \sqrt{\text{Watts} \div \text{Resistance}} \\ \text{Volts} &= \text{Resistance} \times \text{Amperes} \\ &= \text{Watts} \div \text{Amperes} \\ &= \sqrt{\text{Watts} \times \text{Resistance}} \end{aligned}$$

Inductances in series.

$$L = L_1 + L_2 + L_3 + \dots$$

Condensers in parallel.

$$C = C_1 + C_2 + C_3 + \dots$$

Condensers in series.

$$C = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \dots}$$

Condensers in series-parallel.

$$C = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{\frac{1}{C_3} + \frac{1}{C_4}} + \dots}$$

Capacity is calculated by the charge which must be transmitted to a body to lift its potential one unit. A capacity of one farad needs one coulomb of electricity to increase its potential by one volt. Charged with a quantity  $A$  to a potential  $E$  a conductor has a capacity  $K$  equal to :—

$$A \div E$$

Amperage of alternating current in circuits which include resistance and inductance is equal to :—

$$\frac{V}{\sqrt{S^2 + (6.28 FL)^2}}$$

where  $F$  is the frequency in cycles per second,  $L$  the inductance in henries current will be expressed in virtual amperes where  $S$  is in ohms and  $V$  in virtual volts. The denominator gives the impedance of the circuit in question.

For circuits also involving a capacity  $K$  in farads, the impedance is then equal to :—

$$\frac{V}{\sqrt{B^2 + (6.28FK - \frac{1}{6.28FK})^2}}$$

Current in a simple circuit.—The current in a circuit including a cell of electromotive force  $V$ , an external resistance  $Y$  and internal resistance  $P$  is equal to :—

$$\frac{V}{Y + P} \text{ amperes}$$

For two cells in parallel the amperage is equal to :—

$$\frac{V}{Y + \frac{P}{2}}$$

For two cells in series the amperage is equal to :—

$$\frac{V}{Y + 2P}$$

Conductivity is measured by the amount of electricity moved across a unit area, per unit potential rise in unit time.  $S$  is the reciprocal of resistivity. Specific conductance or volume conductivity is equal to :—

$$\frac{1}{S}$$

where  $V$  is the volume resistivity. Equivalent conductivity  $E$  is equal to :—

$$S \div W$$

where  $W$  is the number of equivalents per unit volume of solution. Mass conductivity is equal to :—

$$\frac{S}{D}$$

where  $D$  is density.

The dielectric constant of a medium is shown by  $E$  in the equation :—

$$A = \frac{BD}{EU^2}$$

where  $A$  is the force of attraction between two charges  $B$  and  $D$  parted by a distance  $U$  in a uniform medium.

Hysteresis.—The magnetization of a mass of iron or steel due to a magnetic field which is made to alter through a cycle of value, lags behind the field. This effect is known as hysteresis.

Steinmetz' equation for hysteresis states that the loss of energy in ergs per cycle per cubic centimetre is equal to :—

$$CM^{1.6}$$

where  $M$  is the maximum induction in maxwells per  $\text{cm}^2$  and  $C$  the coefficient of hysteresis.



**Force between two magnetic poles.**—If two poles of strength  $V$  and  $W$  are separated by a distance  $D$  in a medium whose permeability is  $P$ , the force between them is equal to :—

$$\frac{VW}{PD^2} \text{ dynes}$$

when the permeability of a vacuum is unity. Here  $D$  is in cm. and  $V$  and  $W$  are in cgs. units of pole strength. The strength of a magnetic field at a point distant  $D$  from an isolated pole of strength  $K$  is equal to :—

$$\frac{K}{PD^2} \text{ gauss}$$

Here  $K$  and  $D$  are in cgs units.

**Faraday's law.**—The mass of substance decomposed by the passing of the same amount of electricity through different electrolytic cells are, for the same electrolyte, equal, and for different electrolytes are in ratio to the combining weight of the elements which are deposited.

**Induced electromotive force** in a circuit is in ratio to the amount of alteration of magnetic flux through the circuit and is equal to :—

$$-\frac{A}{B} \text{ volts}$$

where  $A$  is the change of magnetic flux in a time  $B$ . The current induced is equal to :—

$$\frac{A}{CB}$$

where  $C$  is the resistance of the circuit.

**Heat effect.**—The heat caused in a circuit by an electric current of  $A$  amperes flowing through a resistance of  $R$  ohms, with a difference of potential of  $V$  volts for a time  $T$  seconds is equal to :—

$$\frac{VAT}{4.18} \text{ or } \frac{TRA^2}{4.18} \text{ calories}$$

**Kirchoff's laws.**—(a) The algebraic sum of the currents which meet at any point is equal to zero.

(b) The algebraic sum of the products of the current and the resistance in each conductor in a closed circuit is equal to the electromotive force in the stated circuit.

**Magnetic field due to a magnet.**—At a point on the magnetic axis extended at a distance  $S$  cm. from the magnet centre, the length of magnet being  $R$  cms. whose poles are  $+P$  and  $-P$  and magnetic moment  $T$ , the field strength is equal to :—

$$2SRP \div \left[ S^2 - \left( \frac{R}{2} \right)^2 \right]^{3/2} \text{ gauss}$$

If  $S$  is large compared with  $\frac{R}{2}$  then the field is equal to :—

$$2T \div S^3$$

**Magnetic field due to a current.**—The strength of the magnetic field at the midpoint of a round conductor of radius  $R$  and in which a current  $C$  in absolute electromagnetic units is passing is equal to :—

$$\frac{6.28MC}{R} \text{ gauss}$$

If the circular coil has  $M$  turns the magnetic intensity at the centre is equal to :—

$$\frac{6.28MC}{R} \text{ gauss}$$

The magnetic field in a long single layer coil of  $M$  turns per centimetre length passing a current  $C$  in absolute electromagnetic units is equal to :—

$$12.56MC \text{ gauss}$$

If  $C$  is given in amperes the above formulae then become equal to :—

$$\frac{6.28C}{10R}, \quad \frac{6.28MC}{10R}, \quad 1.256MC.$$

**Lenz's law.**—When an electromotive force is caused in a conductor by an alteration in the relation between the magnetic field and conductor, the electromotive force direction is such as to produce a current whose magnetic field will oppose the change.

**The magnetic field.**—At a point on a line cutting the magnet into two right angles, is equal to :—

$$RP \div \left[ \left( \frac{R}{2} \right)^2 + S^2 \right]^{3/2} \text{ gauss}$$

The magnetic field for large values of  $r$  is equal to :—

$$T \div S^3 \text{ gauss}$$

The electrostatic unit of charge is the quantity which, if concentrated at a point and set at unit distance from an equivalent and similarly concentrated amount, is repelled with unit force. If the distance is one cm. and the force of repulsion one dyne and the surrounding medium is a vacuum, this is equivalent to one electrostatic unit of quantity. The electromagnetic unit of quantity, is known as the amount transferred by unit current in unit time. The quantity passed by one ampere in one second is called the coulomb. The faraday is the electrical charge carried by one gram equivalent. The coulomb is equal to :—

$$3 \times 10^9 \text{ electrostatic units}$$

The time of frequency of vibration of a magnet of magnetic moment  $A$  and moment of inertia  $B$  oscillating in a field of strength  $G$  is equal to :—

$$6.28 \sqrt{B \div GA} \text{ seconds}$$

The power developed by an electric current in watts passing in a conductor where V is the difference of potential at its ends in volts, R is its resistance in ohms, and A the current in amperes is equal to :—

RA<sup>2</sup> or AV watts

The work done in Joules in a time S secs. is equal to :—

SRA<sup>2</sup> or ASV joules

The power for alternating current in a circuit is equal to :—

AV cos P watts

where V and A are the effective values of the electromotive force and current in volts and amperes and P the phase angle between the current and the impressed electromotive force and the ratio watts ÷ AVWcos P is known as the power factor.

The tangent galvanometer has A turns, or radius R in the earth's field F and has a deflection K<sup>1</sup> then the current flowing is equal to :—

$$\tan K^1 \frac{RF}{6.28A}$$

Torque produced by the effect of one magnet on another.—The turning moment felt by a magnet of pole strength M and length R put at a distance K from another magnet of length S and pole strength N where the axis of the first is perpendicular to the axis of the second, and the centre of the first magnet is on the extended axis of the second one, then the torque is equal to :—

$$\frac{NMRS}{4(K^2)} \theta.$$

If the first magnet is turned through angle A, the formula for the torque is equal to :—

$$\frac{NMRS}{4(K^2)} \cos A$$

The pulling effect of a magnet with induction K has a pole face of area B the force then being equal to :—

$$K^2 B \dots 25.132$$

### SPECIFIC RESISTANCE

$$R = \frac{T P}{A}$$

Where T = specific resistance of a centimetre cube, P = length of wire in cm. A = cross sectional area of wire in sq. cms. and R = the resistance of the wire at 0° C. If T is in Microhms R is in microhms If T is in ohms, R is in ohms.

### SPECIFIC RESISTANCES OF MATERIALS

Material	Resistance in Microhms per cm. cube	Material	Resistance in Microhms per cm. cube
Silver ... ..	1.47	Mercury ... ..	94.07
Copper ... ..	1.588	Manganin ... ..	46.7
Aluminium ... ..	2.665	Eureka ... ..	51.0
Iron ... ..	9.07	Nichrome ... ..	95.0
Platinum ... ..	10.92	Water ... ..	7 × 10 <sup>14</sup>
Tin ... ..	13.05	Mica... ..	5 × 10 <sup>23</sup>
Lead ... ..	20.4	Glass ... ..	5 × 10 <sup>24</sup>

1 microhm = .00001 of an ohm

### DATA ON ALTERNATING CURRENTS

Ohms Law for A.C. is modified as follows :—

$$A = \frac{E}{\sqrt{[R^2 + (LM - \frac{1}{C})^2]}}$$

Where E = voltage, A = amperes, R = ohms resistance, C = capacitance in farads, L = inductance in henries, F = frequency, and M = 2πF.

Note for 50 cycles supply M = 314.16

" " 60 " " M = 376.99

Special formula for Resistance only A = E ÷ R

" " " Capacitance only A = ECM

" " " Inductance only A = E ÷ LM

R.M.S. (Root mean Square) values, is the value of A.C. that has the same heating effect as D.C.

In the case of Sine Waves which generally apply

Maximum value = π ÷ 2 average value = √2 R.M.S. value.

Form Factor =  $\frac{\text{R.M.S. value}}{\text{Average value}} = \frac{\pi}{2\sqrt{2}}$  Average Value = 2 ÷ π × maximum value.

Power Factor = P.F or equivalent cos Ø.  
=  $\frac{\text{Watts}}{\text{Volts} \times \text{Amps.}}$

P.F. is equal to the cosine of the angle of lag between voltage and current in the case of Sine Waves.

Power in A.C. circuits.—Single Phase Watts = Volts × amps. × cos Ø.

2 phase Watts = 2 × volts × amps. × cos Ø. 3 phase Watts = √3 × volts × amps. × cos Ø.  
Where in each case the amps. is the line current and volts the voltage between lines. (This is incorrect for common wires in 2 and 3 phase circuits.)

Delta connection 3 phase motors. Voltage across phase windings = Line Volts. Current in phase windings = Line current ÷ √3.

Star connections, 3 phase motors. Voltage across phase windings = Line Volts  $\div \sqrt{3}$ . Current in phase windings = Line current.

Three-phase supply.—The black wire is neutral and the red, green, and white wires are the 3 phase leads. If single phase connection is desired use neutral and any one of the three coloured wires. Three-phase voltage between phase-wires is equal to  $\sqrt{3}$   $\times$  single phase voltage.

#### USEFUL FORMULAE

Theoretical power of single phase circuit in K.V.A. = (Volts  $\times$  Amps.)  $\div$  1,000  
 Real power of single phase circuit in kilowatts = (Volts  $\times$  Amps.  $\times$  P.F.)  $\div$  1,000.  
 Apparent power of 2-phase circuit in K.V.A. = (2  $\times$  Volts  $\times$  Amps.)  $\div$  1,000.  
 Real power of 2-phase circuit in Kilowatts = (2  $\times$  Volts  $\times$  Amps.  $\times$  P.F.)  $\div$  1,000.  
 Theoretical power of 3-phase circuit in K.V.A. = (1.73  $\times$  Volts  $\times$  Amps.)  $\div$  1,000.  
 Real power of 3-phase circuit in Kilowatts = (1.73  $\times$  Volts  $\times$  Amps.  $\times$  P.F.)  $\div$  1,000.  
 Input of 1, 2, or 3-phase Motor in K.V.A. = (H.P.  $\times$  .746)  $\div$  (Efficiency  $\times$  P.F.)  
 Output of 1, 2 or 3-phase Motors in H.P. = (Input in K.V.A.  $\times$  Efficiency  $\times$  P.F.)  $\div$  .746

#### RADIO FORMULAS AND LAWS WAVELENGTH OF A TUNED CIRCUIT

$W = 1884.96 \sqrt{LC}$ . where L = inductance in microhenries, and C = capacity in microfarads.

#### FREQUENCY OF A TUNED CIRCUIT

$f = \frac{10^8}{2\pi \sqrt{LC}}$ . where f = frequency in cycles per second and h and C have values as shown in the previous formula.

#### INDUCTANCE OF A COIL

$L = \pi^2 d^2 n^2 T K$  where L = inductance in microhenries, d = diameter of coil in cms., n = number of turns per cm., T = length of coil in cms., and K = a constant depending on ratio of diameter to length of coil. Value for K given below.

d/T	K	d/T	K	d/T	K
.00	4.00	.8	.735	4.0	.365
.1	.959	.9	.711	5.0	.320
.2	.920	1.0	.688	6.0	.285
.3	.884	1.5	.595	7.0	.258
.4	.850	2.0	.526	8.0	.237
.5	.818	2.5	.472	9.0	.218
.6	.788	3.0	.429	10.0	.203
.7	.761				

#### VARIABLE CONDENSER CAPACITY

$$C = \frac{.0885 NS}{10^6 d}$$

Where N = number of moving vanes, S = area of one moving vane in sq. cms., and d = thickness of air gap between fixed and moving vanes in cms.

#### REACTANCE OF A COIL

$R = 2\pi fh$  where f = frequency in c.p.s. and h = inductance in henries.

#### REACTANCE OF A CONDENSER

$R = \frac{1}{2\pi fc}$  where f = frequency in c.p.s. and C = capacity in farads.

#### WAVELENGTH

$W = 1884 \sqrt{LC}$  where W = metres, L = inductance in microhenries, C = capacity in microfarads. Also  $W \times f = 3 \times 10^8$ .

#### LOW FREQUENCY AMPLIFICATION

The voltage stage gain of an L.F. transformer coupled-amplifier is approximately as follows :—

$$A = \mu \frac{N_2}{N_1} \times \frac{P}{\sqrt{P^2 + R^2}}$$

Where  $\mu$  = voltage gain of valve,  $N_2$  = number of secondary turns of transformer,  $N_1$  = number of primary turns of transformer, R = A.C. resistance of valve, and P = reactance of primary coil in ohms.

#### RESISTANCE COUPLED L.F. AMPLIFICATION

Voltage stage gain of a resistance coupled L.F. amplifier is as follows :—

$$A = \mu \times \frac{R}{R+T}$$

where  $\mu$  = amplification factor of valve, R = external coupling resistance on ohms, and T = A.C. resistance (impedance) of valve.

#### CAPACITY OF FIXED CONDENSERS

$$C = \frac{.0885 AP (n-1)}{d}$$

$$\text{Reactance of a condenser} = \frac{1}{2\pi fc}$$

Where :—

C = capacity in farads

A = area of overlap of plates in sq. cms.

P = dielectric constant of separating material

n = number of metal plates

d = distance separating plates in cms.

f = frequency in cycles per seconds

Dielectric constants of insulating materials commonly used.

Air = 1. Glass = 6.6 to 10. Mica = 5 to 7. Ebonite = 2.56 to 3.48. Shellac = 2.95 to 3.73. Fibre = 5.1 to 5.9. India rubber (Para) = 2.34. Paraffin Wax = 1.92 to 2.47. Vulcanised Rubber = 2.94.

## LIGHT

**Conjugate foci.**—In correct conditions light divergent from a point near or on the axis of a lens or spherical mirror is focused at another point. The point of convergence and the source position are interchangeable and are known as conjugate foci.

**Lambert's law of absorption.**—If A is the original intensity and B the intensity after passing through a thickness C of a substance with absorption coefficient D, then :—  

$$B = A(2.718^{-cD})$$

**Achromatic** means practically complete correction for chromatic aberration in lenses.

**Chromatic aberration.**—Because of the difference in the index of refraction for different wavelengths, the light of different wavelengths coming from the same source cannot be focused at a point by a simple lens. This is known as chromatic aberration.

**Diffraction.**—If the light source were a point, the shadow of any object would have its greatest sharpness. A certain amount of light would be found within the geometrical shadow because of the diffraction of the light at the object's edge.

**Brewster's law.**—The polarising angle tangent for a material is equal to the refractive index. The polarising angle is that angle of incidence for which the reflected polarised ray is at right angles to the refracted ray.

**Intensity of light** in candle meters of a screen lightened by a source of illuminating power of A candles at a distance of S meters, for normal incidence is equal to :—  

$$A - S^2$$

If two sources of illuminating power A and B produce equal lighting on a screen when at distances C and D respectively, then :—

$$\frac{A}{C^2} = \frac{B}{D^2} \text{ or } \frac{A}{B} = \frac{C^2}{D^2}$$

If E is the strength of light when the screen is normal to the incident light and F the strength when at an angle H then :—

$$F = E \cos H$$

**Luminous strength** is the capability of a source of giving out luminous flux and may be reckoned by the luminous flux emitted per unit solid angle. The unit of light intensity is the international candle. The Hefner unit is equal to .9 international candles and is the strength of a lamp of standard type burning amyl acetate and known as the Hefner lamp.

The mean spherical candle-power is the man candle-power measured in all directions and is equivalent to the total luminous flux in lumens divided by 12.566. The mean horizontal candle-power is the average strength measured in a horizontal plane passing through the source.

**Lambert's law.**—When illumination is normally incident on a perfectly diffusing surface the strength of the reflected illumination is in ratio to the cosine of the angle made with the normal.

The magnifying power of an optical instrument is the proportion of the angle subtended by the image of the object visible through the instrument to the angle subtended by the object when seen by the naked eye. In the case of the simple magnifier or microscope, the object as viewed by the naked eye is supposed to be at a distance of 10 in.

The minimum change of direction of light passing through a prism is at a minimum when the angle of incidence is equal to the angle of emergence. If B is the angle of minimum deviation and C the angle of the prism, the index of refraction of the prism for the wavelength used is equal to :— $\sin \frac{1}{2}(C+B) \div \sin \frac{1}{2}C$

**Radius of curvature** from spherometer readings. If A is the mean length of the sides of the triangle formed by the points of the three legs of the spherometer, B the spherometer readings, the radius of curvature of the surface is equal to :— $(A^2 + 6B) \div (B \div 2)$

**Photographic density.**—The density P of silver deposit on a photographic plate or film is set by the ratio :—  
 $P = \log K$  when K is the opacity. If A and B are the incident and transmitted strength respectively, the opacity is given by  $A - B$ . Transparency is the reciprocal of opacity and is equal to  $B - A$ .

**Polarised light** is light which shows different characteristics in different directions at right angles to the line of propagation. Specific rotation is the capability of liquids to turn the polarization plane. It is reckoned in terms of specific rotation or the rotation in degrees per decimetre per unit density.

**Principal focus** of a spherical mirror or lens is the point of convergence of light coming from a source at an infinite distance.

**Light reflection by a transparent medium in air.**—(Fresnel's formulae.) If A is the incidence angle, R the angle of refraction, B the index of refraction for air being practically equal to unity, D index of refraction for a medium, then the proportion of the reflected light to the incident light is equal to :—

$$\frac{[\sin^2(A-R) + \tan^2(A-R)]}{[\sin^2(A+R) + \tan^2(A+R)]} \div 2$$

## POSITION OF OBJECT AND IMAGE RELATIONS

- Distance of object from mirror or lens A
- Distance of image from mirror or lens B.
- Focal length of mirror or lens C.
- Radius of curvature of mirror D = 2 × focal length.
- Distances checked on the same side of the mirror or lens as the object are positive and those on the opposite side negative.

**Spherical mirror:**—
$$\frac{2}{D} = \frac{1}{A} + \frac{1}{B}$$

(For concave mirror, D is +. For convex mirror, D is —.)

**Lens.** 
$$\frac{1}{SD} + \frac{1}{A}$$

(For concave or divergent lens,  $\downarrow$ D is +. For convex or convergent lens,  $\downarrow$ D is —.)

The speed of light through the atmosphere is 186,335 miles per second. The speed of light through transparent bodies is not definitely known, but probably varies inversely as to the square root of the specific gravity of the transparent substance.

Light passes from the sun to the earth in about eight minutes, at which speed light can pass around the earth in .125 of a second.

### TO FIND THE FOCAL LENGTH OF A CONVEX MIRROR

Use as object an opaque screen, with a hole and pin-point, and painted white, or coated with white paper.

Set up on the test table in line with the left edge of the hole, the convex mirror and an auxiliary biconvex lens of short focal length of approximately 5 inches, and set the lens so that the hole image and pin-point is formed side by side with the object. The mirror centre is now at the position at which the image would be formed by the lens alone; this site may either be reckoned or found, after noting the site of the mirror and then removing it, by means of a screen. So the radius is easily measured.

If the mirror focal length is more than D, that of the lens, the easiest way of setting is to put the lens as near as possible to the mirror, put the object at lens principal focus, and adjust the object back until the image is formed as above.

If, however, the focal length is less, we can be sure of discovering the site by placing the mirror at a distance of 4D from the object, and the lens at 2D, and placing the lens back until the required place is arrived at.

### TO FIND THE FOCAL LENGTH OF A CONCAVE LENS

Use an object similar to the one mentioned above, an auxiliary convex lens of approximately 5 inches focal length, to give a convergent beam, and an auxiliary plane mirror, put beyond the concave lens.

Move until the image is formed side by side with the object, as previously; then the rays must be emerging parallel to one another from the concave lens, and therefore the convergent beam from the convex lens will, if the concave lens and mirror are removed, form an image at the principal focus of the concave lens. A direct measure can therefore be got of the focal length.

The resolving power of a telescope or microscope is shown by the smallest separation of two objects by which they seem distinct and apart when seen through the instrument.

*Formulae for spherical mirrors.*—If C is the radius of curvature, P principal focus, and D and E any two conjugate focal distances, then :—

$$\frac{1}{E} + \frac{1}{D} = \frac{2}{C} = \frac{1}{P}$$

If the linear dimensions of the image and object be A and B respectively and C and D their distances from the mirror, then :—

$$\frac{D}{C} = \frac{B}{A}$$

*Rotatory power* is the capability of turning the plane of polarized light, given in general by A - B where A is the whole rotation which takes place in a distance B.

*Spherical aberration.*—When large areas of lenses or spherical mirrors are utilised the light divergent from a point source is not precisely focused at a point. This characteristic is called spherical aberration. For axial pencils the error is known as axial spherical aberration; or if for oblique pencils, coma.

*Specific rotation.*—If there are A grams of active substance in B cubic centimetres of solution and the light passes through D centimetres, R being the observed rotation in degrees, the specific rotation for one centimetre is equal to :—

$$\frac{BR}{DA}$$

*Snell's law of refraction.*—If A is the angle of incidence, R the angle of refraction, B the velocity of light in the first medium, D the velocity in the second medium, then the index of refraction is equal to :—  
B - D or sin A - sin R

*Total reflection.*—When light passes from any medium to one in which the velocity of passing is higher, refraction ends and total reflection starts at a certain critical angle of incidence A such that

$$\sin A \text{ is equal to } \frac{1}{M}$$

where M is the index of the first medium with respect to the second. If the second medium is air, M has the ordinary value for the first medium. For any other second medium, then

$$\frac{C}{D} = M$$

where C and D are the ordinary indices of refraction for the first and second medium respectively.

### SPECTRUM DECOMPOSITION OF LIGHT

Colour Combinations.	Primary	Secondary	Tertiary
Yellow	}	Orange ...	Brown
Red			
Blue	}	Purple ...	Dark Green
Red			
Blue	}	Green ...	
Yellow			

*Maximum rays of colours.*—Violet, Indigo, Blue, Green, Yellow, Orange, Red  
 Chemical ——— Electrical ——— Light ——— Heat

## HYDRAULICS

**Viscosity.**—All liquids have a resistance to alteration of shape and a number of solids display a gradual giving to forces trying to alter their shape. This property, which is a type of internal friction, is known as viscosity; it is denoted in dyne-seconds per cm.<sup>2</sup> or poises. If the tangential force per unit area, effected by a fluid layer upon one next to it, is one dyne for a space rate of change of the tangential velocity of unity, the viscosity is one poise.

Kinematic viscosity is the proportion of viscosity to density.

**Speed of outflow of a liquid.**—If H is the height of the free surface of the liquid above the opening, the speed of outflow is equal to :—

$$\sqrt{64.358H}$$

This is the theoretical discharge speed without reckoning friction and the shape of the opening. For water pouring through a round aperture with sharp edges of area, M, the volume discharged per second is equal approximately to :—

$$.62M \sqrt{64.358H}$$

**Flow of fluids through a tube.**—Where P is the length of the tube, R its radius, N the difference of pressure at the end, V the coefficient of viscosity, the quantity released per second is equal to :—

$$\frac{3.1416N}{8PV} (R^4) \text{ cubic centimetres per second}$$

If P and R are in cm., N in dynes per cm.<sup>2</sup> and V in dyne-seconds per cm.<sup>2</sup>, where the dyne is equal to .00102 grams.

**Stoke's law** gives the velocity of falling of a small globe in a viscous fluid. When a small globe falls under the action of gravity through a viscous medium it eventually reaches a constant velocity V which is equal to :—

$$\frac{64.348B^2 (C-D)}{9P}$$

where B is the radius of the globe, C and D the coefficient of viscosity. V is in cm.<sup>3</sup> per sec. If gravity is in cm. per sec.<sup>2</sup>, B in cm., C and D in grams per cm.<sup>2</sup> and P in dyne-sec. per cm.<sup>2</sup> or poises.

**Hydrostatic pressure** at a distance B from the surface of a liquid of density M is equal to :—

$$32.174(BM) = T$$

The total force on an area S caused by hydrostatic pressure is equal to

$$TS = SBM(32.174)$$

The force in dynes and pressure in dynes per cm.<sup>2</sup> can be arrived at if B is in cm., M in grams per cm.<sup>3</sup> and gravity in cm. per sec.<sup>2</sup>.

**Pascal's law.**—Pressure applied at any point upon a confined liquid is transmitted without reduction in all directions.

## BUOYANCY

Buoyancy centre is the point of application of the upward pressure of pressure of fluid, and acts at the centre of area of the immersed part.

The instantaneous centre of rotation of floating body is the metacentre.

Metacentric height is the distance between the floating body centre of gravity and the metacentre.

C = volume of water displaced by body.

T = centre of gravity of floating body.

D = centre of buoyancy.

E = moment of inertia of the water plane of the floating body about a longitudinal axis.

W = metacentre.

K = weight of cubic feet of liquid.

$$DW = \frac{E}{C}$$

Metacentric height = WD—TD = WT.

Upward pressure of water = KT.

## STATIC PRESSURE OF A LIQUID

The centre of pressure of an immersed area is the application point of the resultant pressure of the liquid.

The head of a fluid is the equivalent height of a column of the fluid which gives the same pressure.

S = area of immersed surface.

M = pressure per sq. ft.

E = moment of inertia of S about water surface.

K = weight of cub. ft. of liquid.

D = depth of centre of area of S below surface.

F = head of liquid.

$$M = KF$$

Whole pressure on surface = KSD

Centre of pressure =  $\frac{2\text{nd moment of area about water surface}}{1\text{st moment of area about water surface}}$

$$\text{Depth} = \frac{E}{SD}$$

## LIQUID FRICTION AND FLOW THROUGH PIPES

- A = head lost in friction.  
 B and C = length and diameter of pipe in ft.  
 D = frictional coefficient.  
 E = mean speed in pipe.  
 F = difference of head at inlet and outlet of pipe.  
 $A = 4DBE^2 \div 64.35C$   
 $F = \frac{1.5E^2}{64.35} + A = \frac{E^2}{64.35} \left( \frac{4DB}{C} + 1.5 \right)$

### HEAD LOSSES

- Due to sudden enlargement =  $(V-W)^2 \div 64.35$   
 At pipe entrance =  $(.5V)^2 \div 64.35$   
 Due to friction =  $4ACV^2 \div 64.35B$   
 where A = length of pipe  
       B = diameter of pipe  
       C = a frictional coefficient.  
 Due to sudden contraction =  $(.5V)^2 \div 64.35$   
 where V and W are the commencing and final speeds.

## WEIRS AND NOTCHES

### OUTLETS

- A = coefficient of discharge.  
 B = area of orifice.  
 C = head causing flow.  
 Time of emptying a tank of area S =  $\frac{25\sqrt{C}}{AB\sqrt{64.35}}$

- Rate of discharge =  $AB\sqrt{64.35C}$   
 A = length of notch or weir in ft.  
 B = height of water surface above the sill in ft.  
 Discharge through rectangular notch =  $1.5A\sqrt{64.35}AB^{1.5}$  per sec.  
 Discharge through triangular notch =  $.533A\sqrt{64.35}\tan .5FB^{2.5}$   
 where F° = notch angle.

For large weirs.—Formula (a) =  $B^{1.5}(A - 1/8B) 3.333$

Formula (b) =  $Z\sqrt{64.35}AB^{1.5}$

where  $Z = .405 + \frac{.00984}{B}$

Forced Vortex.—Centrifugal head.

- A = angular velocity of fluid.  
 B and D = outside and inside radii of fluid.

Centrifugal head =  $\frac{A^2}{64.35}(B^2 - D^2)$

Venturi Meter.

- A = meter constant.  
 B = sectional area of pipe in sq. ft.  
 C = sectional area of throat in sq. ft.  
 D = actual measured head.  
 E = frictional coefficient of meter.

$$A = \frac{BC\sqrt{64.35}}{\sqrt{B^2 - C^2}}$$

Quantity of flow =  $AE\sqrt{D}$

## LIQUID FLOW

- A = velocity of liquid in ft. per sec.  
 g = acceleration due to gravity 32.2 ft. per sec. per sec.  
 M = area of cross-section of pipe or channel in sq. ft.  
 K = weight in cu. ft. of liquid.

Velocity head of liquid =  $\frac{A^2}{64.35}$

Quantity of flow per sec. = MA in cu. ft.

Kinetic energy =  $\frac{KMA^2}{64.35}$





## CENTRIFUGAL PUMPS

Key same as given under Water Turbines.

Work done by Impeller = (JE) - 32.17

Manometric efficiency =  $\frac{\text{Pipe losses} + \text{Actual Lift}}{(\text{JE}) - 32.17}$

For least speed of starting :-

$$\text{Efficiency (JE - 32.17)} = \frac{E^2}{64.35} - \frac{D^6}{64.35}$$

Horse power needed = (VJD) - 16,500

$$b = 6.28 \text{ MBZ} = 6.28 \text{ NLa}$$

Specific speed =  $(\sqrt{Vb}) - W^{.75}$

## WATER TURBINES

Relative speed is the water speed in relation to the blade.

100 Reaction turbine.—The water pressure falls as it flows through the wheel. The turbine must run per cent. full.

Speed of whirl is the tangential component of the absolute speed of the water

Speed of flow is the radial component of the absolute speed of the water.

Impulse turbine has water at normal atmospheric pressure and the turbine does not run 100 per cent. full

## NEWTON'S THEOREM OF SUCCESSIVE APPROXIMATIONS

This can be used for solving any equation with only one unknown, and is particularly useful for solving equation which would be difficult or impossible by any other method.

Consider the equation  $y = f(x)$  where  $y$  is known. Assume  $x_1$  as a first approximation to the value of  $x$ , and let this give  $y_1$  as the value of  $f(x_1)$ , then a second approximation to  $x$  much better than  $x_1$  will be

$$x_2 = x_1 - \frac{y_1 - y}{dy_1 - dx_1}$$

For example solve for  $x^5 + x = 33.7$

here  $y = 33.7$ , take  $x_1 = 2$

$$\therefore y_1 = 2^5 + 2$$

$$\text{or } y_1 = 34.$$

$$\text{Now } dy \div dx = 5x^4 + 1$$

$$\therefore dy_1 \div dx_1 = 5 \times 2^4 + 1 = 81$$

$$\therefore x_2 = 2 - \frac{34 - 33.7}{81} = 1.9963$$

which is a much better approximation than  $x_1$  to the true value of  $x$ . By repeating the process with 1.9963 instead of 2 an even better third approximation  $x_3$  can be obtained, viz :-

$$x_3 = 1.9963 - \frac{(1.9963^5 + 1.9963) - 33.7}{5(1.9963)^4 + 1}$$

This process can be continued indefinitely until such degree of accuracy as is required in the result is obtained.

## USEFUL CONSTANTS

$\pi$	=	3.14159	$g$	=	32.16
$3 \div \pi$	=	.95492	$1 \div 2g$	=	.01555
$\pi^2$	=	9.8696	$\pi \div \sqrt{g}$	=	.55399
$\sqrt{\pi}$	=	1.77245	$\sqrt[3]{6 \div \pi}$	=	1.2407
$1 \div \sqrt[3]{\pi}$	=	.68278	$\pi \div 3$	=	1.0472
$\pi \div 4$	=	.7854	$1 \div \pi$	=	.31831
$2g$	=	64.32	$1 \div \pi^2$	=	.10132
$1 \div \sqrt{g}$	=	.17634	$\sqrt[3]{\pi}$	=	1.46459
$\pi \div 180$	=	.01745	$\sqrt[3]{3 \div 4\pi}$	=	.62035
$2\pi$	=	6.28318	$g^2$	=	1034.226
$4\pi \div 3$	=	4.18879	$\sqrt{2g}$	=	8.01998
$\pi^3$	=	31.00628	$e$	=	2.71828
$1 \div \sqrt{\pi}$	=	.56419	$180^\circ \div \pi$	=	57.2958°
$\sqrt[3]{\pi^2}$	=	2.14503			

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