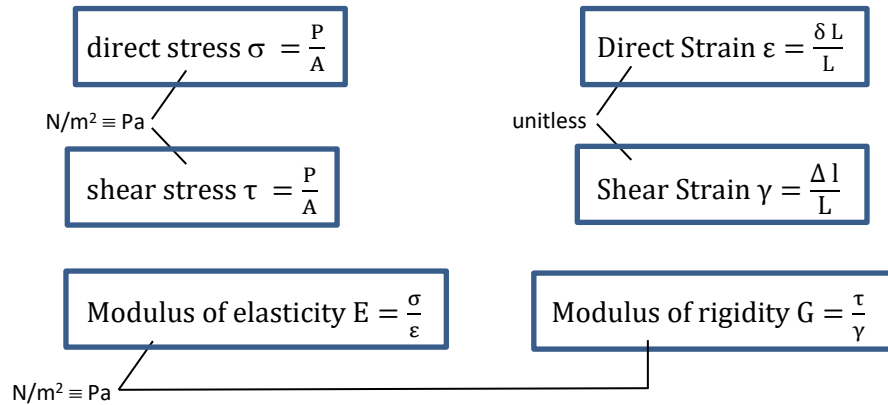


FORMULEA BOOKLET

I. Stress and Strain, Modulus of Elasticity and Rigidity:



II. Equilibrium Condition of Forces and Moments

Moment $M = F \times d$ (Unit: $N.m$)

Condition for static equilibrium:

$$\begin{cases} \text{sum of the } \textbf{leftward} \text{ component of forces} = \text{sum of the } \textbf{rightward} \text{ component of forces} \\ \text{sum of the } \textbf{upward} \text{ component of forces} = \text{sum of the } \textbf{downward} \text{ component of forces} \end{cases}$$

III. Dynamics

1. Linear motion:

Newton's Second Law for linear systems:

$$\Sigma F = m \cdot a$$

Linear motion of bodies moving with constant acceleration:

$$\begin{aligned} v &= v_0 + a \cdot t & (1) \\ v^2 &= v_0^2 + 2 \cdot a \cdot s & (2) \\ s &= v_0 \cdot t + \frac{1}{2} \cdot a \cdot t^2 & (3) \\ s &= \frac{1}{2} \cdot (v + v_0) \cdot t & (4) \end{aligned}$$

Where:

v_0 = initial velocity at $t = 0$
 a = constant acceleration

v = velocity at time t
 s = displacement

2. Rotational Motion:

Relationships between linear and angular speed:

linear speed $v = r \cdot \omega$ angular speed
m/s rad/s

Relationships between angular speed and frequency of rotation:

angular speed $\omega = 2 \cdot \pi \cdot n$ frequency
rad/s rev/s

Relationships between linear and angular acceleration:

linear acceleration $a = r \cdot \alpha$ angular acceleration
m/s² rad/s²

Rotational motion of bodies moving with constant angular acceleration:

$$\omega = \omega_0 + \alpha \cdot t \quad (1)$$

$$\omega^2 = \omega_0^2 + 2 \cdot \alpha \cdot \theta \quad (2)$$

$$\theta = \omega_0 \cdot t + \frac{1}{2} \cdot \alpha \cdot t^2 \quad (3)$$

$$\theta = \frac{1}{2} \cdot (\omega + \omega_0) \cdot t \quad (4)$$

Where: ω_0 = initial angular velocity at $t = 0$ ω = angular velocity at time t
 α = constant angular acceleration θ = angle turned through in time t

Newton's Second Law for rotating systems:

$$\sum M = I \cdot \alpha$$

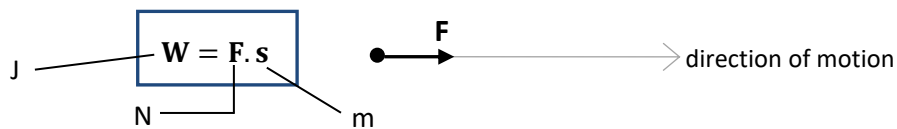
Where Second Moment of Inertia I is:

Moment of Inertia $I = m \cdot k^2$ k is the radius of gyration in m
in kg.m²

IV. Work, Energy and Power

1. Work:

- a. The work done by a **constant force** is given by



- b. Suppose that a **constant force** F acts on a body so as to move it in a direction other than its own



The component of F in the direction of motion is $F \cos \theta$, in which case the work done W is given by

$$W = F \cdot s \cdot \cos \theta$$

- c. Work done by a torque T

$$W = T \cdot \theta$$

2. Energy:

- a. Kinetic energy for a body undergoing translational motion

$$KE = \frac{1}{2} \cdot m \cdot v^2$$

- b. Kinetic energy for a body undergoing rotational motion

$$\text{Rotational KE} = \frac{1}{2} \cdot I \cdot \omega^2$$

- c. Total kinetic energy of a rolling wheel

$$\text{total kinetic energy} = \frac{1}{2} m v^2 + \frac{1}{2} I \omega^2$$

- d. Gravitational Potential Energy

$$PE = m \cdot g \cdot h$$

- e. Work-Energy Principle

$$\left(\begin{array}{c} \text{work done by} \\ \text{external forces} \end{array} \right) = \left(\begin{array}{c} \text{change in} \\ KE \end{array} \right) + \left(\begin{array}{c} \text{change in} \\ PE \end{array} \right)$$

3. Power:

a. First expression

If a machine is working at a steady rate, the power of the machine is

$$\text{Watt (W)} \rightarrow \boxed{\text{power} = \frac{\text{work done}}{\text{time taken}}}$$

When the rate of working is not steady, the above equation give the average power.

b. Instantaneous Power

$$\boxed{\text{power} = \text{force} \times \text{speed} = F.v}$$

c. Power developed by a torque T applied to rotate an axle through an angle θ in time t

$$\boxed{\begin{array}{l} \text{power developed} \\ \text{by a torque} \end{array} = \frac{T.\theta}{t} = T.\omega}$$

d. Efficiency η

$$\boxed{\eta = \frac{\text{work output}}{\text{work input}} \text{ in a given time}}$$

$$\boxed{\eta = \frac{\text{power output}}{\text{power input}}}$$

$$\boxed{\eta = \frac{\text{energy output}}{\text{energy input}} \text{ in a given time}}$$

Example:

$$\text{Efficiency } \eta \text{ of a car} = \frac{\text{power car}}{\text{power engine}}$$

V. Fluid Flow

1. Density ρ :

$$\text{kg/m}^3 \rightarrow \boxed{\rho = \frac{m}{V}}$$

The **density of water** is usually taken to be **1000 kg/m³** although the value:

- decreases slowly as temperature increases,
- increases very slowly as pressure increases.

2. Specific Weight γ :

$$\gamma = \rho \cdot g$$

N/m^3 kg/m^3 m/s^2

Definition of
Newton

$$N \equiv kg \cdot \frac{m}{s^2}$$

3. Specific Gravity or Relative Density:

$$\text{Relative Density} = \frac{\text{Density of substance}}{\text{Density of water (at } 4^\circ\text{C)}}$$

unitless

4. Pressure:

N/m^2 or bar

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

$$1 \text{ bar} \equiv 10^5 \text{ N/m}^2$$

5. Compressibility:

m^2 / N

$$\text{compressibility} = \frac{\text{change in volume}}{\text{original volume} \times \text{pressure change}}$$

6. Pressure energy of unit mass or specific pressure energy:

$$\text{specific pressure energy} = \frac{P}{\rho}$$

J / kg N / m^2 or bar kg / m^3

7. Total specific energy E:

$$E = \frac{P}{\rho} + \frac{v^2}{2} + g \cdot h$$

J / kg

h is the height of the fluid above some datum line.

8. Bernoulli's equation:

$$\frac{P_1}{\rho \cdot g} + \frac{v_1^2}{2 \cdot g} + h_1 = \frac{P_2}{\rho \cdot g} + \frac{v_2^2}{2 \cdot g} + h_2 + h_f$$

where h_f is the frictional resistance "head"

Each quantity in the latter form of the Bernoulli's equation is measured in terms of "head of fluid", i.e. height of liquid above a given datum. The unit for each quantity is the meter.

Therefore,

$$\begin{aligned} & (\text{pressure head} + \text{kinetic head} + \text{potential head}) \text{ all for the section 1} \\ & = \\ & (\text{pressure head} + \text{kinetic head} + \text{potential head} + \text{frictional resistance head}) \text{ all for the section 2} \end{aligned}$$

9. Continuity equation:

$$\text{mass flow rate } \dot{m} \text{ (kg/s)} = \text{volume flow rate} \times \text{density } \rho$$

$$\text{volume flow rate } Q \text{ (m}^3\text{/s)} = \text{area} \times \text{velocity}$$

$$Q = A_1 \cdot v_1 = A_2 \cdot v_2$$

Extra Notes:

- 1 cubic meter is equal to 1,000 litres:

$$1 \text{ m}^3 \equiv 1000 \text{ l}$$

- For water:

$$1 \text{ kg} \equiv 1 \text{ l} \quad (\text{for water})$$

- The energy lost in friction, i.e. the loss of power, is given by:

$$\text{loss of power} = \text{mass flow rate} \times g \times h_f$$

J/s or Watt
kg / s
m / s²
m

VI. Heat Transfer

1. Conduction

Fourier's law of heat conduction (1D, steady-state)

$$Q = -k \cdot A \cdot \frac{dT}{dx}$$

Where the derivative term dT/dx is called the temperature gradient; k is called the thermal conductivity which is a material property; A is the surface area of the material considered; Q is the steady heat flow rate through the material, i.e. the amount of heat transferred, i.e. heat leakage, i.e. heat loss.

a. Plane wall with fixed surface temperatures / Conduction through composite wall.

$$Q = -U \cdot A \cdot (T_2 - T_1)$$

T as for units °C or Kelvin. Δx as for units m. A as for units m². k as for units W/(m.°C) or W/(m.K). Q as for units W. U is either the heat transfer coefficient $U = k/x$ or the overall heat transfer coefficient $1/U = 1/U_a + 1/U_b + 1/U_c + \dots$

b. Radial system with fixed surface temperatures.

For a single-layer cylindrical wall of a homogeneous material with constant thermal conductivity and uniform inner (1) and outer (2) surface temperatures:

$$Q = \frac{2\pi kL(T_1 - T_2)}{\ln\left(\frac{r_2}{r_1}\right)}$$

For a two layer cylinder the heat transfer rate is:

$$Q = \frac{2\pi L(T_1 - T_3)}{\frac{1}{k_a} \ln\left(\frac{r_2}{r_1}\right) + \frac{1}{k_b} \ln\left(\frac{r_3}{r_2}\right)}$$

2. Convection

Without regard to the classification of convection, the heat flow between a solid and a fluid is governed by Newton's law of cooling, defined by:

$$Q = h \cdot A \cdot (T_s - T_f)$$

Where Q is the rate of heat transfer by convection, in W; h is the convective heat transfer coefficient, in W/m².K; A is the surface area of the solid in contact with the fluid, in m²; T_s is the temperature at the surface of the solid, in K; T_f is the temperature of the fluid stream, in K.

3. Radiation**a. The Stefan-Boltzmann Law**

$$Q = \varepsilon \cdot \sigma \cdot A \cdot T^4$$

Where Q is the energy radiated by the surface, in kW; A is the surface area of the body, in m²; ε is the emissivity of the surface (varies between 0 and 1) at the temperature T ; σ is the Stefan-Boltzmann constant, 56.7×10^{-12} kW/m²K⁴; T is the temperature of the body, in K. In practice, bodies do not radiate into perfect *heat sinks* (bodies that can absorb finite amounts of heat without undergoing any change in temperature) but also receive radiation from the surroundings. Thus if the body is at a temperature T_2 and the surroundings at a lower temperature T_1 , the nett loss is given by:

$$Q = 56.7 \cdot \varepsilon \cdot A \cdot \left[\left(\frac{T_2}{1000} \right)^4 - \left(\frac{T_1}{1000} \right)^4 \right]$$

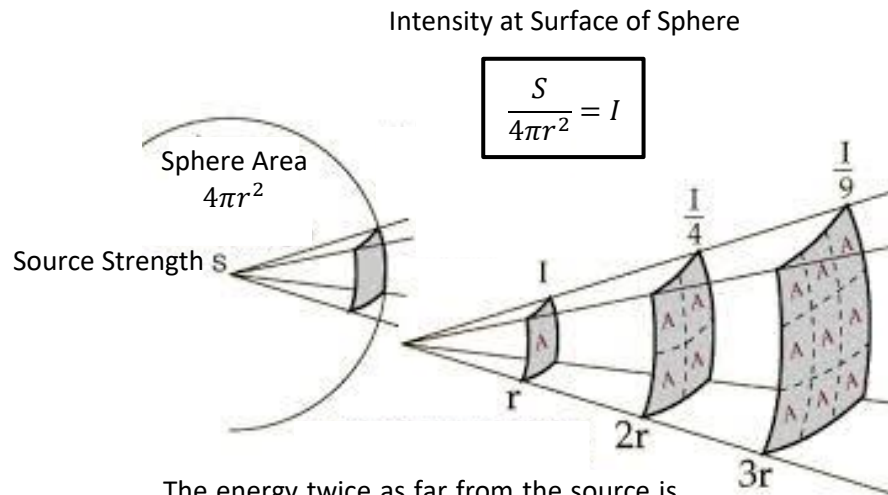
Difficulty is experienced when the body is outside, since it is hard to determine the sky radiation temperature. On a cold night, the sky radiation temperature will be of the order of 230 K. During the day, the sky temperature is often taken to be about 5°C below ambient. The re-radiation from the atmosphere is often known as diffuse radiation and expressed as a percentage of the direct solar radiation.

Emissivity varies with temperature and also throughout the spectrum. For simplified analysis, the emissivity is often taken as an approximate mean value, as shown in following Table.

Material	Emissivity ε
Polished aluminium	0.095
Oxidised (corroded) aluminium	0.2
Anodised (anti-corrosion) aluminium	0.95
Polished steel	0.07
Oxidised steel	0.8
Asbestos	0.95
Building brick	0.45
Water and Ice	0.96

A surface with an emissivity of 1 defines a black body

b. The Inverse Square Law



The energy twice as far from the source is spread over four times the area, hence one-fourth the intensity.

$$^{\circ}\text{C} = \text{K} - 273.15$$

$$\text{K} = ^{\circ}\text{C} + 273.15$$