This formula booklet has been prepared to assist students sitting Fire Engineering Science papers in the IFE examinations. It is intended to supplement other learning and draws together the main formula that students should understand and be comfortable using. Many other formulas can be derived from those given in this booklet. The 2017 version has been enhanced to include changes to the Level 4 Certificate syllabus.
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Note: Students preparing for the level 4 paper should also be familiar with the science and formulae included in Section 1 of this booklet.

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## 1. EQUATIONS OF LINEAR MOTION

<table>
<thead>
<tr>
<th>Equation</th>
<th>Quantities</th>
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<tbody>
<tr>
<td>$v = u + at$</td>
<td>✓</td>
</tr>
<tr>
<td>$s = \frac{(u + v)}{2}t$</td>
<td>✓</td>
</tr>
<tr>
<td>$s = ut + \frac{1}{2}at^2$</td>
<td>✓</td>
</tr>
<tr>
<td>$s = vt - \frac{1}{2}at^2$</td>
<td>✓</td>
</tr>
<tr>
<td>$v^2 = u^2 + 2as$</td>
<td>✓</td>
</tr>
</tbody>
</table>

Where:
- $v$ = Final velocity in metres per second (m/s)
- $u$ = Initial velocity in metres per second (m/s)
- $a$ = Acceleration in metres per second per second (m/s$^2$ or m.s$^{-2}$)
- $t$ = Time in seconds (s)
- $s$ = Distance travelled in metres (m)

It should be noted that all of these formulae are derived from two basic formulae of linear motion:

$$\text{Velocity}(v) = \frac{\text{distance travelled (s – in meters)}}{\text{time taken (t – in seconds)}}$$

and

$$\text{Acceleration}(a) = \frac{\text{velocity (v – meters per second)}}{\text{time taken (t – in seconds)}}$$
2. **NEWTON’S LAWS OF MOTION**

1. **Newton’s First Law:** An object continues in its state of rest or of uniform motion in a straight line unless acted upon by an external force.

2. **Newton’s Second Law:** A change in motion (acceleration) is proportional to the force acting and takes place in the direction of the straight line along which the force acts.

   Acting force = mass x acceleration caused

   or, \( F = m \times a \)

3. **Newton’s Third Law:** To every action there is an equal and opposite reaction (or, if object A exerts a force on object B, then object B exerts an equal, but oppositely-directed, force on A).
3. MASS, WEIGHT AND MOMENTUM

\[ F = m \times a \]  
(NEWTONS SECOND LAW)

Where: \( F = \) Force in newtons (N)  
\( m = \) Mass in kilogrammes (Kg)  
\( a = \) Acceleration due to gravity (constant) in metres/second/second (m/s\(^2\))  
(use 9.81 m/s\(^2\))

\[ P = \mu R \]

Where: \( P = \) Pushing (or applied) force in newtons (N)  
\( \mu = \) Friction factor (normally between 0.2 and 1)  
\( R = \) Reaction force exerted by the floor in newtons (N)

\[ R - F = 0 \quad \text{and} \quad P - F_r = 0 \]

Where: \( P = \) Pushing (or applied) force in newtons (N)  
\( F_r = \) Reactive friction force opposing the pushing force in newtons (N)

Note: These formula apply when the object is at rest or moving at a constant velocity.

**Pressure and Force**

\[ P = \frac{F}{A} \]

Where: \( P = \) Pressure in Pascals (P)  
\( F = \) Force in Newtons (N)  
\( A = \) Area in square meters (m\(^2\))

**Momentum**

\[ mu = m \times v \]

Where: \( mu = \) Momentum in kilogram meters per second (kg.m.s\(^{-1}\))  
\( m = \) Mass of object in kilograms (kg)  
\( v = \) Velocity of object in meters per second (m.s\(^{-1}\))
4. WORK, ENERGY AND POWER

\[ P = \frac{F \times d}{t} \]

Where:  
\( P \) = Power in watts (W)  
\( F \) = Force in newtons (N)  
\( d \) = Distance in metres (m)  
\( t \) = Time taken in seconds (s)

\[ \text{Efficiency} = \frac{\text{useful output energy}}{\text{input energy}} \]

or

\[ \text{Efficiency} = \frac{\text{useful output power}}{\text{input power}} \]

\[ W = Pt \]

Where:  
\( W \) = Work done (J)  
\( P \) = Power in watts (W)  
\( t \) = Time taken (s)

\[ W = Fd \]

Where:  
\( W \) = Work done (J)  
\( F \) = Force (N)  
\( d \) = Distance (m)

\[ KE = \frac{1}{2}mv^2 \]

Where:  
\( KE \) = Kinetic energy in Joules (J)  
\( m \) = Mass in Kilogrammes (Kg)  
\( v \) = Velocity in metres per second (m/s)
\[ PE = mgh \]

Where:
- \( PE \) = Potential (gravitational) energy in Joules (J)
- \( m \) = Mass in Kilogrammes (Kg)
- \( g \) = Acceleration due to gravity (constant) in metres/second/second (m/s\(^2\))
  (use 9.81 m/s\(^2\))
- \( H \) = Height of object above datum in metres (m)

Note: The potential energy calculated here is the energy of the object when held at height ‘H’ above the datum level.

\[ v = \sqrt{2gh} \]

Where:
- \( v \) = Velocity in metres per second (m/s)
- \( g \) = Acceleration due to gravity (constant) in metres/second/second (m/s\(^2\))
  (use 9.81 m/s\(^2\))
- \( H \) = Height of object above datum in metres (m)

Note: The velocity calculated here is the velocity when the object reaches the datum level, when released from height ‘H’ above the datum level.
HYDRAULICS

\[ P = \rho g H \]

Where:  
\( P \) = Pressure in Pascal  
\( \rho \) = Density of the fluid (normally 1000 kg/m\(^3\) for fresh water)  
\( g \) = Acceleration due to gravity (constant 9.81 m/s\(^2\))  
\( H \) = Head (or depth) of fluid in metres

For fire ground use, this simplifies to:

\[ P = \frac{H}{10} \text{ or } H = 10P \]

Where:  
\( P \) = Pressure in bar  
\( H \) = Head in metres

Pressure loss due to Friction

\[ P_f = \frac{9000flL^2}{d^5} \]

Where:  
\( P_f \) = Pressure loss due to friction in bar  
\( f \) = Friction factor for the hose (normally given in the question)  
\( l \) = Length of the hose in metres  
\( L \) = Flow rate in litres per minute  
\( d \) = Diameter of the hose in millimetres

Flow through a Nozzle

\[ L = \frac{2}{3} d^2 \sqrt{P} \]

Where:  
\( L \) = Flow rate in litres per minute  
\( d \) = Diameter of the nozzle in millimetres  
\( P \) = Pressure in bar

Water power and Efficiency

\[ WP = \frac{100LP}{60} \]

Where:  
\( WP \) = Water Power in Watts  
\( L \) = Flow rate in litres per minute  
\( P \) = Pressure in bar
\[ E = \frac{WP}{BP} \times 100 \]

Where:
- \( E \) = Efficiency of a pump (\%)
- \( WP \) = Water Power in Watts
- \( BP \) = Brake Power of engine in Watts

Jet Reaction

\[ R = 0.157 P d^2 \]

Where:
- \( R \) = Jet reaction in newtons
- \( P \) = Pressure in bar
- \( d \) = Diameter of the hose in millimetres

Effective Height of a Jet

\[ H_e = \frac{2}{3} \left( H - 0.113 \frac{H^2}{d} \right) \]

Where:
- \( H_e \) = Effective height of jet in meters
- \( H \) = Theoretical height to which water will rise when projected vertically from nozzle in meters
- \( d \) = Diameter of nozzle in millimetres

Note: \( H \) can be calculated from the velocity or pressure of the water leaving the nozzle, using:

\[ H = 10P \quad \text{or} \quad H = \frac{v^2}{2g} \]

Actual tests have shown that the actual height of the highest drops can be approximated from:

\[ H - 0.113 \frac{H^2}{d} \]

and that an effective firefighting stream can only be expected to achieve two thirds of that height.
6. **MATHEMATICS**

**Area of a Circle**

\[ A = \pi r^2 \quad \text{or} \quad A = \frac{\pi d^2}{4} \]

Where:
- \( A \) = Area of circle in metres squared (m\(^2\))
- \( \pi \) = Pi (constant – use 3.1416)
- \( r \) = Radius of circle in metres
- \( d \) = Diameter of circle in metres

**Volumes**

- Sloping tank = length \( \times \) breadth \( \times \) average depth
- Circular tank (cylinder) = \( A = \pi r^2 \times \text{depth} \) or \( A = \frac{\pi d^2}{4} \times \text{depth} \)
- Cone or pyramid = \( \frac{\text{area of base} \times \text{vertical height}}{3} \)
- Sphere = \( \frac{\pi d^3}{6} \) or \( \frac{4\pi r^3}{3} \)

Capacity of a pond = \( \frac{2}{3} \times \text{surface area} \times \text{average depth} \)

(this can be used as a rough approximation to find the amount of water in a pond)

Capacity of container (in litres) = volume (m\(^3\)) \( \times \) 1000

Atmospheric pressure = 101,300 N/m\(^2\) or 1.013 bar

**Pythagoras**

For finding sides of right-angled triangles (and solving vectors).

\[ a^2 + b^2 = c^2 \]
\[ c = \sqrt{a^2 + b^2} \quad a = \sqrt{c^2 - b^2} \quad b = \sqrt{c^2 - a^2} \]

**SOHCAHTOA**

\( \text{SohCahToa} \) is the easy way to remember how the Sine, Cosine and Tangent rules work.
soh… \[ \sin \theta = \text{Opposite} / \text{Hypotenuse} \]

…cah… \[ \cos \theta = \text{Adjacent} / \text{Hypotenuse} \]

…toa… \[ \tan \theta = \text{Opposite} / \text{Adjacent} \]

You can make-up any mnemonic that might help you remember these, such as:

“SOME OFFICERS HAVE CURLY AUBURN HAIR TO OFFER ATTRACTION”.

**BODMAS**

The acronym BODMAS defines the order of operations of mathematical functions. "Operations" mean things like add, subtract, multiply, divide, squaring, etc. If it isn’t a number it is probably an operation.

The Correct order is:
- Brackets (parenthesis)
- Orders (powers and square roots)
- Division and multiplication
- Addition and subtraction

Sometimes called BIDMAS, where the ‘I’ stands for Indices (or powers).

**Example**

- **Do things in Brackets First.** Example:
  - \( 6 \times (5 + 3) = 6 \times 8 = 48 \)
  - \( 6 \times (5 + 3) = 30 + 3 = 33 \) (wrong)

- **Exponents (Powers, Roots) before Multiply, Divide, Add or Subtract.** Example:
  - \( 5 \times 2^3 = 5 \times 4 = 20 \)
  - \( 5 \times 2^2 = 10^2 = 100 \) (wrong)

- **Multiply or Divide before you Add or Subtract.** Example:
  - \( 2 + 5 \times 3 = 2 + 15 = 17 \)
  - \( 2 + 5 \times 3 = 7 \times 3 = 21 \) (wrong)

- **Otherwise just go left to right.** Example:
  - \( 30 + 5 \times 3 = 18 \)
  - \( 30 + 5 \times 3 = 30 + 15 = 2 \) (wrong)
Sine and Cosine Rules

To solve a triangle is to find the lengths of each of its sides and all its angles. The sine rule is used when we are given either two angles and one side, or two sides and a non-included angle. This works for all triangles (not just right-angled triangles):

\[
\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}
\]

The cosine rule is used when we are given either three sides or two sides and the included angle. Again, this works for all triangles:

\[
a^2 = b^2 + c^2 - 2bc \cos A \\
b^2 = a^2 + c^2 - 2ac \cos B \\
c^2 = a^2 + b^2 - 2ab \cos C
\]

SI Units

SI units are standard units (units agreed internationally by a committee that meets periodically in Switzerland). Most equations rely on values being presented in SI units and candidates should therefore be able to convert values given in exam question to SI units before using them in calculations.

For example, values of density should be presented in kg/m\(^3\). An exam question may give a value in g/ml (grams per millilitre) and this would therefore need to be converted before use.

A conversion factor must be derived from the units given. Take each unit in turn and work-out how to convert it. Let’s use a sample value of 1.4 g/ml:

First, grams to kilograms: One kilogram = 1000 grams, so the value must be divided by 1000

Then, millilitres to cubic meters: There are 1000 litres in a cubic meter and 1000 millilitres in a litre. The value must therefore be multiplied by 1000 x 1000 = 1.4\times10^6

Therefore, the new value = \(\frac{1.4\times10^6}{1000} = 1.4\times10^3\) kg/m\(^3\)

Understanding a value’s units

Some confusion may arise regarding the units shown against a value. There are a number of different ways of displaying units in an acceptable. Examples are shown below:

For displaying the units for the density of a substance, we might write

\(Kg/m^3\) or \(kg.m^{-3}\) or \(\frac{kg}{m^3}\)

All of these are correct but the third is rarely used. The first and second are both common and are interchangeable.

REMEMBER: You will drop a point if you do not state the units in your answer.
7. EQUILIBRIUM IN MECHANICAL SYSTEMS

Conditions for Equilibrium

1. If an object is moving in a straight line, without accelerating or decelerating, the total (resultant or net) force acting on it must be zero.

2. If an object is not rotating, the total (resultant or net) moment (or turning force) acting on it must be zero.

Condition 1: Parallel forces acting on a beam, supported at both ends

![Beam Diagram]

Total Upward Force = Total Downward Force

\[ A + D = B + C \]

Condition 1: Non-Parallel Forces (vector forces)

![Vector Diagram]

Solve by drawing a vector diagram to represent the forces. Represent the 500N vertical force with a 5cm vertical line. From the bottom of the line, add a 3.6cm line at 30°. Then join the two ends to form a triangle. The length and angle of the third line gives the third force (260N) and angle (43.7°). These values can be confirmed by calculations using the Sine and Cosine rule.
Condition 2: Bending Moments (rotating)

Moment of a Force = Force x Distance

Take moments about a Point (i.e. for point A):

\[ 0 = + (B \times d_1) + (C \times d_2) - (D \times d_3) \]

…or about Point D:

\[ 0 = + (A \times d_4) - (B \times d_5) - (C \times d_6) \]
8. ELECTRICITY

\( V = IR \)

Where:

\( V \) = Voltage in volts
\( I \) = Current in Amps
\( R \) = Resistance in ohms (\( \Omega \))

\( P = IV \)

Where:

\( P \) = Power in Watts
\( V \) = Voltage in volts
\( I \) = Current in Amps

Power can also be calculated from:

\[
Power (P) = \frac{Work\ done (J)}{Time\ taken (s)}
\]

Resistors in series:

\( R_T = R_1 + R_2 + R_3 \)

Resistors in Parallel:

\[
\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}
\]

Resistivity:

\( R = \frac{\rho l}{a} \)

Where:

\( R \) = Resistance in ohms (\( \Omega \))
\( \rho \) = Resistivity of conductor material in ohms-meter (\( \Omega \cdot m \))
\( l \) = Length of cable in metres (m)
\( a \) = Cross sectional area in square metres (m\(^2\))
$R_t = R_0(1 + \alpha t)$

Where:

- $R_t$ = Final resistance of coil when heated to $t^\circ\text{C}$ in ohms ($\Omega$)
- $R_0$ = Resistance of coil at $0^\circ\text{C}$ in ohms ($\Omega$)
- $\alpha$ = Temperature coefficient of resistance of a material in ohms (per $^\circ\text{C}$)
- $t$ = Final temperature in degrees centigrade ($^\circ\text{C}$)

When two temperatures are given (i.e. when the starting temperature is not $0^\circ\text{C}$):

$$\frac{R_0}{R_t} = \frac{1 + \alpha_0 t_{ref}}{1 + \alpha_0 t_{final}}$$

Where:

- $R_0$ = Initial resistance of coil when heated to $t_1^\circ\text{C}$ in ohms ($\Omega$)
- $R_t$ = Final resistance of coil when heated to $t_2^\circ\text{C}$ in ohms ($\Omega$)
- $\alpha_0$ = Temperature coefficient of resistance of a material in (per $^\circ\text{C}$)
- $t_{ref}$ = Initial reference temperature in degrees centigrade ($^\circ\text{C}$)
- $t_{final}$ = Final temperature in degrees centigrade ($^\circ\text{C}$)

The "alpha" ($\alpha$) constant is known as the temperature coefficient of resistance, and symbolizes the resistance change factor per degree of temperature change. Just as all materials have a certain specific resistance (at $20^\circ\text{C}$ – room temperature), they also change resistance according to temperature by certain amounts. For pure metals, this coefficient is a positive number, meaning that resistance increases with increasing temperature. For the elements carbon, silicon, and germanium, this coefficient is a negative number, meaning that resistance decreases with increasing temperature. For some metal alloys, the temperature coefficient of resistance is very close to zero, meaning that the resistance hardly changes at all with variations in temperature (a good property if you want to build a precision resistor out of metal wire!).

A more useful representation of this formula for finding $R_t$:

$$R_t = R_0\left[1 + \alpha(t_{final} - t_{ref})\right]$$

Or, transposing to find $t_{final}$:

$$t_{final} = \left(\frac{R_t}{R_0} - 1\right)\frac{\alpha}{\alpha} + t_{ref}$$
Heat is a form of energy and is measured in joules.

**Absolute Zero** = 0 K (Kelvin), or -273 °C

To convert: °C to K
\[ K = °C + 273 \]

To convert: K to °C
\[ °C = K - 273 \]

**Thermal Capacity of a Body** = Heat required to raise temperature of body (anything!) by 1 °C without changing its state.

Or, as a formula: \[ c = \frac{\Delta Q}{\Delta T} \]

Where: \[ c = \text{Heat required (joules per degree centigrade J}^{\circ}\text{C)} \]
\[ \Delta Q = \text{Heat transferred (joules J)} \]
\[ \Delta T = \text{Change in temperature (}^{\circ}\text{C)} \]

**Specific Heat Capacity (C)** = Heat required to raise temperature of 1 gram of substance by 1 °C (or 1 K) without changing its state – in J/g/°C or J/Kg/K

\[ c = \frac{\Delta Q}{m \times \Delta t} \]

Where: \[ c = \text{Specific Heat Capacity of substance (in J/Kg}^{\circ}\text{C)} \]
\[ \Delta Q = \text{Heat lost/change (in joules)} \]
\[ m = \text{Mass of substance (in Kg)} \]
\[ \Delta t = \text{Change in temperature (in °C or K)} \]

**Latent Heat** = Heat taken-in or given-out when a substance changes state
(e.g. from solid to liquid or liquid to gas)

**Specific Latent Heat of Fusion** = Amount of heat required to change 1 Kg of solid at its melting point to a liquid (with the temperature remaining constant). Opposite effect is Specific Latent Heat of Solidification.

**Specific Latent Heat of Vaporisation** = Amount of heat required to change 1 Kg of a liquid to a gas (the liquid being at its boiling point). Opposite effect is Specific Latent Heat of Condensation.
**Enthalpy** = measure of the total energy of a thermodynamic system.

Enthalpy:
\[ \Delta H_{\text{Fusion}} = - \Delta H_{\text{Solidification}} \]
\[ \Delta H_{\text{Vaporisation}} = - \Delta H_{\text{Condensation}} \]

**Expansion**

**Co-efficient of Linear Expansion** = Increase in unit length per degree rise in temperature

**Linear** expansion is two-dimensional expansion, e.g. the change in the length of a steel beam through heating (Note: The beam will expand in three dimensions but if we are only interested in the change in length, we will calculate the linear expansion the less significant expansion in the second and third dimensions).

\[ L_{\text{Exp}} = l \times \alpha \times \Delta T \]

Where:
- \( L_{\text{Exp}} \) = Expansion (in metres)
- \( l \) = Length before heating (in metres)
- \( \alpha \) = Coefficient of linear expansion
- \( \Delta T \) = Change in temperature (in °C or K)

**Co-efficient of Superficial Expansion** = Increase in unit area per degree rise in temperature

**Superficial** (or areal) expansion is a change in the area of the sides of a solid material through heating.

\[ A_{\text{Exp}} = A \times 2 \times \alpha \times \Delta T \]

Where:
- \( A_{\text{Exp}} \) = Increase in area (in square metres)
- \( A \) = Area before heating (in square metres)
- \( \alpha \) = Coefficient of linear expansion
- \( \Delta T \) = Change in temperature (in °C or K)

**Co-efficient of Cubical Expansion** = Increase in unit volume per degree rise in temperature

**Cubical** (or volumetric) expansion is three-dimensional expansion, e.g. the change in volume of a sphere through heating.

\[ V_{\text{Exp}} = V \times 3 \times \alpha \times \Delta T \]
Where: \( V_{\text{Exp}} = \) Expansion in volume (in cubic metres)
\( V = \) Volume of beam before heating (in cubic metres)
\( \alpha = \) Coefficient of linear expansion
\( \Delta T = \) Change in temperature (in °C or K)

Coefficient of **superficial** expansion = 2 x Coefficient of **linear** expansion
Coefficient of **cubical** expansion = 3 x Coefficient of **linear** expansion

For a solid, the linear expansion is linked to the superficial expansion and the cubical expansion.

For liquids and gases there is just cubical expansion.
10. **THE GAS LAWS**

**Boyle’s Law**

The volume of a given mass of gas is inversely proportional to the pressure upon it if the temperature remains constant.

\[ P_1 \times V_1 = P_2 \times V_2 \]

Where:
- \( P_1 \) = Initial pressure (in bar)
- \( V_1 \) = Initial volume (in cubic metres)
- \( P_2 \) = Final pressure (in bar)
- \( V_2 \) = Final volume (in cubic metres)

**Charles’s Law** *(also known as the law of volumes)*

The volume of a given mass of gas is directly proportional to the temperature of the gas in kelvin.

\[ \frac{V_1}{T_1} = \frac{V_2}{T_2} \]

Where:
- \( V_1 \) = Initial volume (in cubic metres)
- \( T_1 \) = Initial temperature (in Kelvin)
- \( V_2 \) = Final volume (in cubic metres)
- \( T_2 \) = Final temperature (in Kelvin)

**The Law of Pressures** *(also known as the Gay-Lusacc’s Law)*

The pressure exerted on a container’s sides by an ideal gas is proportional to its temperature.

\[ \frac{P_1}{T_1} = \frac{P_2}{T_2} \]

Where:
- \( P_1 \) = Initial pressure (in bar)
- \( T_1 \) = Initial temperature (in Kelvin)
- \( P_2 \) = Final pressure (in bar)
- \( T_2 \) = Final temperature (in Kelvin)
The Combined Gas Law (or General Gas Equation)

Combination of previous laws:

\[
\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}
\]

Where:
- \(P_1\) = Initial pressure (in Bar)
- \(V_1\) = Initial volume (in cubic metres)
- \(T_1\) = Initial temperature (in Kelvin)
- \(P_2\) = Final pressure (in Bar)
- \(V_2\) = Final volume (in cubic metres)
- \(T_2\) = Final temperature (in Kelvin)

The Ideal Gas Equation

\[PV = nRT\]

This can also be expressed as: \(PV = NkT\)

Where:
- \(P\) = Absolute pressure
- \(V\) = Absolute volume
- \(n\) = Number of moles
- \(R\) = universal gas constant (8.3145 J/mol K)
- \(T\) = Absolute temperature
- \(N\) = Number or molecules
- \(k\) = Boltzmann constant (1.38066 \(\times\) 10\(^{-23}\))

**Note:** When using the gas laws all temperatures must be in Kelvin.
11. TRANSFORMER RATIOS

\[
\frac{V_P}{V_S} = \frac{N_P}{N_S} = \frac{I_S}{I_P}
\]

Where:
- \( V_P \) = Primary (applied) voltage in volts (V)
- \( V_S \) = Secondary (output) voltage in volts (V)
- \( N_P \) = Primary windings (count of turns)
- \( N_S \) = Secondary windings (count of turns)
- \( I_P \) = Current in primary windings in amps (A)
- \( I_S \) = Current in secondary windings in amps (A)
SECTION 2: L4 CERTIFICATE – FIRE ENGINEERING SCIENCE

For the Level 4 Certificate, students will need to be familiar with all of the formula shown above for Level 3 Diploma students, plus those shown below, which are specific to the Level 4 Certificate syllabus.

12. HYDRAULICS

Bernoulli’s Equation

Bernoulli’s equation describes the relationship between pressure energy, potential energy and kinetic energy in a system. These forms of energy can be interchanged but unless energy is added to, or taken out or a system, the total energy present remains constant at any point. When writing Bernoulli’s equation, each term must stand alone as a true representation of the form of energy concerned.

\[ P_1 + \rho g H_1 + \frac{1}{2} \rho v_1^2 = P_2 + \rho g H_2 + \frac{1}{2} \rho v_2^2 \]

This may also be displayed as:

\[ \frac{P_1}{\rho g} + \frac{v_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{v_2^2}{2g} + Z_2 \]

Where:
- \( P \) = pressure in Pascal
- \( \rho \) = Density of the fluid (normally 1000 kg/m\(^3\) for fresh water)
- \( g \) = acceleration due to gravity (constant 9.81 m/s\(^2\))
- \( H \) or \( Z \) = Height in metres
- \( v \) = velocity of water in metres per second

Liquid Flow in pipes – Pressure loss due to friction

\[ H_f = \frac{2flv^2}{Dg} \]

Where:
- \( H_f \) = pressure loss (Head) due to friction (in metres head)
- \( f \) = friction factor due to roughness of the pipe (no units)
- \( l \) = Length of hose (in metres)
- \( v \) = velocity of water (in metres per second)
- \( D \) = Diameter of hose (in metres)
- \( g \) = acceleration due to gravity (constant 9.81 m/s\(^2\))
By converting metres-head to bar and diameter of hose to millimetres, this may also be expressed as:

\[ P_f = \frac{20fv^2}{d} \]

Where:  
- \( P_f \) = pressure loss due to friction (in bar)  
- \( f \) = friction factor due to roughness of the pipe (no units)  
- \( l \) = Length of hose (in metres)  
- \( v \) = velocity of water (in metres per second)  
- \( d \) = Diameter of hose (in millimetres)

**Continuity Equation**

\[ Q_1 = Q_2 \quad \text{and} \quad A_1 v_1 = A_2 v_2 \]

So:  
- \( Q_1 = A_1 v_1 \) and \( Q_2 = A_2 v_2 \) and \( Q_1 = A_2 v_2 \) and \( Q_2 = A_1 v_1 \)

Where:  
- \( Q \) = Rate of flow (cubic metres per second m³/s)  
- \( A \) = Area (square metres m²)  
- \( v \) = Velocity (metres per second m/s)

**Converting Pressures**

Pressures are often given in different units, and it may be necessary to convert from one value to another. The following table shows the conversions:

<table>
<thead>
<tr>
<th></th>
<th>Pascal</th>
<th>Bar</th>
<th>m/H</th>
<th>N/m²</th>
<th>psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pascal</td>
<td>÷ 100,000</td>
<td>÷ 10,000</td>
<td>x 1</td>
<td>x 6894</td>
<td></td>
</tr>
<tr>
<td>Bar</td>
<td>x 100,000</td>
<td></td>
<td>x 10</td>
<td>x 100,000</td>
<td>÷ 0.07</td>
</tr>
<tr>
<td>m/H</td>
<td>x 10,000</td>
<td>÷ 10</td>
<td></td>
<td>x 10,000</td>
<td>÷ 0.7</td>
</tr>
<tr>
<td>N/m²</td>
<td>x 1</td>
<td>÷ 100,000</td>
<td>÷ 10,000</td>
<td></td>
<td>÷ 6894</td>
</tr>
<tr>
<td>psi</td>
<td>x 6894</td>
<td>x 0.07</td>
<td>x 0.7</td>
<td>x 6894</td>
<td></td>
</tr>
</tbody>
</table>
Force exerted by a jet on a flat surface

\[ F = \rho v^2 A \]

Where:
- \( F \) = Force on plate (in newtons N)
- \( \rho \) = Density of fluid (normally 1000 kg/m\(^3\) for fresh water)
- \( v \) = velocity of water (in metres per second m/s)
- \( A \) = Area of nozzle (in square metres m\(^2\))

Force exerted by a jet on an *inclined* flat surface

\[ F = \rho v^2 A \cos \theta \]

Where:
- \( F \) = Force on plate (in newtons N)
- \( \rho \) = Density of fluid (normally 1000 kg/m\(^3\) for fresh water)
- \( v \) = velocity of water (in metres per second m/s)
- \( A \) = Area of nozzle (in square metres m\(^2\))
- \( \theta \) = Angle of inclination from the vertical (in degrees)
Hydraulic Mean Values

Hydraulic mean radius = \( \frac{\text{cross-sectional area of flow}}{\text{wetted perimeter}} \) or \( m = \frac{A}{p} \)

Where:
- \( m \) = hydraulic mean radius in meters
- \( A \) = area of cross sectional flow square meters
- \( p \) = Wetted perimeter in meters
- \( r \) = radius of pipe in metres

\[
m = \frac{\pi D^2}{4} = \frac{D}{4}
\]

\[
m = \frac{\pi r^2}{2\pi r} = \frac{r}{2}
\]

\[
m = \frac{l^2}{4l} = \frac{l}{4}
\]

\[
m = \frac{h \times b}{2(h+b)}
\]

For the rectangular and trapezoid, the calculations are relatively straight forward, but for the circular channel, the calculations are more complex as they involve calculating the length of an arc of the circle (as the wetted perimeter) and the area of a section of the circle.

The length of an arc can be found from \( \theta = \theta \frac{\pi}{180} r \) degrees

The area of the section of pipe is more complex. The section must be broken into several sections and the area of each found:

- **Section A** is a right-angled triangle.
- **Section B** is a segment of the circle: \( \text{Area} = \frac{r^2}{2} \left( \frac{\pi}{180} \theta - \sin \theta \right) \)
- **Section C** is half a circle: \( \text{Area} = \frac{\pi r^2}{2} \)

Area = (A x 2) + (B x 2) + C

Sufficient dimensions would need to be provided for this calculation.
13. **LIQUID FLOW IN OPEN CHANNELS**

\[ Q = vA \]

Where:  
- \( Q \) = Flow (in \( \text{m}^3 \) per second)  
- \( v \) = velocity of water (in metres per second)  
- \( A \) = Area of cross section of water in open channel (in metres squared)

And ‘\( v \)’ can be found from the ‘Chezy Formula’:

\[ v = C\sqrt{mi} \]

Where:  
- \( v \) = velocity of water (in metres per second)  
- \( C \) = Chezy constant (in \( \text{m}^{1/2}/\text{s} \))  
- \( m \) = Hydraulic mean depth of water (in metres)  
- \( i \) = Incline of the channel (expressed as a ratio)

Note: When entering the incline into the formula, it must be entered as a fraction (e.g. a ratio of 1:150 would be entered as \( \frac{1}{150} \)).
14. MEASURING FLOW THROUGH AN OPEN CHANNEL

Rectangular Weir

\[ Q = \frac{2}{3} \times C \times L \times \sqrt{2g} \times H^{1.5} \]

Where:
- \( Q \) = Flow of water through the weir (in cubic metres per second)
- \( C \) = Weir Coefficient (Chezy constant) (in m\(^{1/2}\)/s)
- \( L \) = Length (or width) of weir (in metres)
- \( g \) = acceleration due to gravity (constant 9.81 m/s\(^2\))
- \( H \) = Head on the weir, measured above the crest (in metres)

Vee-notch Weir

\[ Q = \frac{8}{15} \times C \times \tan \left( \frac{\theta}{2} \right) \times \sqrt{2g} \times H^{2.5} \]

Where:
- \( Q \) = Flow of water through the vee-notch (in cubic metres per second)
- \( C \) = Weir Coefficient (Chezy constant) (in m\(^{1/2}\)/s)
- \( \theta \) = Angle of vee-notch (in degrees)
- \( g \) = acceleration due to gravity (constant 9.81 m/s\(^2\))
- \( H \) = Depth of water in the vee-notch (in metres)
From 2017, the level 4 syllabus has been enhanced to include some additional electrical calculations, for which the following equations will be required:

### Inductive Reactance

\[ X_L = 2\pi fL \]

### Capacitive Reactance

\[ X_C = \frac{1}{2\pi fC} \]

#### Series Circuits

- **Resistors:**
  \[ R_T = R_1 + R_2 \cdots R_n \text{ etc.} \]

#### Parallel Circuits

- **Resistors:**
  \[ \frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} \cdots \frac{1}{R_n} \text{ etc.} \]

  When there are just two resistors in parallel:
  \[ R_T = \frac{R_1 \times R_2}{R_1 + R_2} \]

- **Inductors:**
  \[ L_T = L_1 + L_2 \cdots L_n \text{ etc.} \]

- **Inductors:**
  \[ \frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} \cdots \frac{1}{L_n} \text{ etc.} \]

  When there are just two inductors in parallel:
  \[ L_T = \frac{L_1 \times L_2}{L_1 + L_2} \]

- **Capacitors:**
  \[ \frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} \cdots \frac{1}{C_n} \text{ etc.} \]

  When there are just two capacitors in series:
  \[ C_T = \frac{C_1 \times C_2}{C_1 + C_2} \]

#### Adding voltages: (phasor sum)

\[ V_s = \sqrt{V_R^2 + (V_L - V_C)^2} \]

#### Adding currents: (phasor sum)

\[ I_s = \sqrt{I_R^2 + (I_L - I_C)^2} \]
Series Circuits

<table>
<thead>
<tr>
<th>Total Impedance: (phasor sum)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z = \sqrt{R^2 + (X_L - X_C)^2}$</td>
</tr>
</tbody>
</table>

Parallel Circuits

| $Z = \frac{1}{\sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{X_L} - \frac{1}{X_C}\right)^2}}$ |
| $\frac{1}{Z} = \sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{X_L} - \frac{1}{X_C}\right)^2}$ |
| $Y = \frac{1}{Z}$ |
| $G = \frac{1}{R}$ |
| $B_L = \frac{1}{X_L}$ |
| $B_C = \frac{1}{X_C}$ |
| $Y = \sqrt{G^2 + (B_L - B_C)^2}$ |

Where:

- $V =$ Voltage in volts (V)
- $I =$ Current in Amps (A)
- $L =$ Inductance in Henrys (H)
- $C =$ Capacitance in Farads (F)
- $R =$ Resistance in Ohms (Ω)
- $X_L =$ Reactance in Ohms (Ω)
- $X_C =$ Reactance in Ohms (Ω)
- $Z =$ Impedance in Ohms (Ω)
- $Y =$ Admittance – Reciprocal of Impedance – in Siemens (S)
- $B =$ Susceptance – Reciprocal of Reactance – in Siemens (S)
- $G =$ Conductance – Reciprocal of Resistance – in Siemens (S)

Average Power in AC circuit

$$P_{Avg} = I_{rms}V_{rms}\cos \theta$$

Where:

- $P_{Avg} =$ Average power in the circuit (in watts)
- $I_{rms} =$ RMS current (in amps)
- $V_{rms} =$ RMS voltage (in volts)
- $\cos(\theta) =$ Cosine of the phase angle (or power factor) (no units)
The phasor diagrams below indicate various options for calculating the phase angle of the power factor. Trigonometry SOHCAHTOA rules (see page 11 above) can then be used to calculate the phase angle using whichever values are available.

<table>
<thead>
<tr>
<th>For Series Circuits</th>
<th>For Parallel Circuits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impedance triangle:</td>
<td>Voltage triangle:</td>
</tr>
<tr>
<td>$Z$</td>
<td>$V_s$</td>
</tr>
<tr>
<td>$R$</td>
<td>$V_s$</td>
</tr>
<tr>
<td>$V_c$</td>
<td>$V_c$</td>
</tr>
<tr>
<td>$V_L$</td>
<td>$V_L$</td>
</tr>
<tr>
<td>$V_R$</td>
<td>$V_R$</td>
</tr>
<tr>
<td>$X_L$</td>
<td>$X_L$</td>
</tr>
<tr>
<td>$X_C$</td>
<td>$X_C$</td>
</tr>
<tr>
<td>$\theta$</td>
<td>$\theta$</td>
</tr>
<tr>
<td>$\cos \theta = \frac{R}{Z}$</td>
<td>$\cos \theta = \frac{V_R}{V_s}$</td>
</tr>
<tr>
<td>$\theta = \cos^{-1} \left( \frac{R}{Z} \right)$</td>
<td>$\theta = \cos^{-1} \left( \frac{V_R}{V_s} \right)$</td>
</tr>
<tr>
<td>$\theta = \cos^{-1} \left( \frac{G}{Y} \right)$</td>
<td>$\theta = \cos^{-1} \left( \frac{I_R}{I_S} \right)$</td>
</tr>
<tr>
<td>$\theta = \cos^{-1} \left( \frac{B_C - B_L}{G} \right)$</td>
<td>$\theta = \cos^{-1} \left( \frac{I_C - I_L}{I_R} \right)$</td>
</tr>
<tr>
<td>$\theta = \tan^{-1} \left( \frac{X_L - X_C}{R} \right)$</td>
<td>$\theta = \tan^{-1} \left( \frac{V_L - V_C}{V_R} \right)$</td>
</tr>
<tr>
<td>$\theta = \tan^{-1} \left( \frac{X_L - X_C}{R} \right)$</td>
<td>$\theta = \tan^{-1} \left( \frac{V_L - V_C}{V_R} \right)$</td>
</tr>
</tbody>
</table>

**Power Factor**

The ‘Power Factor’ of the circuit is defined as the ratio of the actual electrical power dissipated by an AC circuit to the product of the r.m.s. values of current and voltage. The difference between the two is caused by reactance in the circuit and represents power that does no useful work. The power factor is usually expressed as the cosine of the angle between useful power and apparent power:

$$PF = \cos \theta$$

There are no units for the power factor as it is a ratio between the useful (true) power (kW) to the total (apparent) power (kVA).

The phase angle $\theta$ can be found from any of the following:

$$\theta = \cos^{-1} \left( \frac{R}{Z} \right) \quad \theta = \cos^{-1} \left( \frac{V_R}{V_s} \right) \quad \theta = \cos^{-1} \left( \frac{G}{Y} \right) \quad \theta = \cos^{-1} \left( \frac{I_R}{I_S} \right)$$

$$\theta = \tan^{-1} \left( \frac{X_L - X_C}{R} \right) \quad \theta = \tan^{-1} \left( \frac{V_L - V_C}{V_R} \right) \quad \theta = \tan^{-1} \left( \frac{B_C - B_L}{G} \right) \quad \theta = \tan^{-1} \left( \frac{I_C - I_L}{I_R} \right)$$

The phase angle is given in degrees. In practice, you don’t need to know all of these formulae. They can all be derived from the phasor diagrams above using trig SOHCAHTOA rules (see page 11 above), depending which values you have available to use. In IFE examination questions involving power factor, be sure to note whether you are being asked to calculate the power factor or the phase angle.

The power factor can be found by combining the above processes; so if:

$$PF = \cos \theta \quad \text{and} \quad \cos \theta = \frac{R}{Z}$$

Then:

$$PF = \frac{R}{Z} \quad \text{or} \quad PF = \frac{V_R}{V_S} \quad \text{or} \quad PF = \frac{G}{Y} \quad \text{or} \quad PF = \frac{I_R}{I_S}$$

Note: This method does not work with the tangent options shown above for finding phase angles because the power factor equals the cosine of the angle.
Law’s Law

When a fire is burning steadily and the composition of the burning material is known, it is possible to calculate the length of time that the fire will burn. The time that the fire will burn (fire resistance) is related to the surface area of the walls and ceilings (excluding the ventilation openings).

Law’s correlation between fire resistance requirement \((t_f)\) and \(L/(A_wA_t)^{1/2}\)

\[
t_f = \frac{k \times L}{\sqrt{(A_w \times A_t)}} \text{ (kg/m}^2)\]

Where:

- \(t_f\) = Time that fire lasts (fire resistance) (min)
- \(L\) = Fire load (Kg)
- \(A_w\) = Area of ventilation (m\(^2\))
- \(A_t\) = Internal surface area of compartment (m\(^2\))
- \(k\) = Constant (near unity, and normally therefore ignored)

By use of this formula, it is possible to calculate the resistance (in minutes) that a door must have to allow for the safe exit of people from a building.
Recommended Calculator

It has been found that the Casio \textit{fx-85GT Plus} is an ideal calculator for use during IFE examinations. This model is inexpensive, readily available throughout the world, fully meets the IFE’s regulations on calculators that may be used and is very easy to operate. It is widely available from high street supermarkets and is used in many schools and colleges. For this reason, this model has been chosen for use at study groups and some guidance is provided herein regarding its use.


This calculator has a large 10+2 Natural textbook Display and shows mathematical expressions like roots and fractions as they appear in your textbook, and this increases comprehension because results are easier to understand.

In particular, students are advised to familiarise themselves with the following functions:

1. Fractions. This button allows you to enter fractions in their natural form, as you see them on the page. Having pressed this button, first enter the value above the line, then press the right arrow (right side of large button) and enter the value below the line. Then press the right arrow again to move outside the fraction.

2. $S\leftrightarrow D$. This button allows you to toggle the result of a calculation between a fraction, a recurring decimal and a decimal number. In most cases, the result will initially be displayed as a fraction so you will need to use this button to obtain a result.

3. To clear the memory of the calculator, press: 0 shift RCL (STO) M+ (M)

4. To clear the contents of all memories: shift 9 (CLR) 2 (Memory) = (Yes)
Revisions

v1.5  
i. Formulae for flow through weirs have been expanded for clarity  
ii. An explanation of ratios has been added in respect of the Chezy formula  
iii. The ideal gas equation has been added to the Gas Laws

v1.6  
iv. Formula for Pythagoras amended on page 10  
v. Definition of Resistivity amended on page 14  
vi. Continuity equation amended on page 22

v1.7  
vii. Formula added for linear motion where ‘u’ is not required on page 3  
viii. Symbol for time changed to ‘t’ for consistency on page 6  
ix. Symbol for velocity standardised as small v

V2.0  
x. Formulae for velocity and acceleration added on page 3  
xii. Formulae added for pressure and momentum on page 5

V2.1  
xiii. Additional formula for power added on page 14

V2.2  
xiv. Formula for effective height of jet added on page 9  
xv. Second version of Bernoulli’s equation added on page 22  
xvi. New section on Electricity added to Section 2 (Level 4) on page 29

V2.2  
xvii. Enhancements made to Calculator instructions on page 33  
xviii. Section on transformer ratios moved to Section 1 to align with syllabus

V2.1  
xix. Sine and Cosine rules added to page 12

V2.2  
xx. Formula added for power in AC circuit on page 30

xxi. Additional material regarding power factors added to page 31