

Engineering Physics

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Engineering Physics 1 [Rotational Mechanics]

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- Angular conversions:** $d = r\theta$ $v = r\omega$ $a = r\alpha$
- Moment of Inertia (I)** kilograms metres squared [kg m^2]
- Moment of Inertia Equation:** $I = \sum mr^2$
[where m is the mass of each point (within the body) and r is its distance from the axis of rotation]
- Angular Momentum (L)** kilogram metres squared per second [$\text{kg m}^2 \text{s}^{-1}$ or N m s]
- Principle of Conservation of Angular Momentum:** In the absence of an external resultant torque the total angular momentum of a system remains constant (i.e. $\Sigma L_{\text{final}} = \Sigma L_{\text{initial}}$).
- Flywheel Uses:** Storing rotational kinetic energy; smoothing torque and/or angular velocity (stores energy when input torque > output torque, supplies energy when input torque < output torque).
- Flywheel advantages:** Efficient; long lasting; short recharge and discharge time; environmentally friendly. [Disadvantages: large and heavy [with high internal mass]; safety risk [fragmentation]; frictional energy loss; gyroscopic effect can interfere with motion if installed in moving body.]

Engineering Physics 2 [Thermodynamics : Concepts]

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- First Law of Thermodynamics:** The *net* thermal energy supplied to the system (Q) is equal to the sum of the *net* internal energy gained by the system (ΔU) and the *net* work done by the system (W).
$$Q = \Delta U + W$$
- Second Law of Thermodynamics:** It is impossible to convert thermal energy continuously to work without at the same time transferring some thermal energy from a hotter to a colder body. [ALT: All real processes occur in such a way that there is a net increase in entropy.]
- Work Done Equation:** $W = p\Delta V$
- Adiabatic Change:** No flow of *thermal energy* into or out of system. Takes place rapidly, leaving *insufficient time* for flow of thermal energy ($\Delta Q = 0 \therefore +\Delta W = -\Delta U$).
- Isothermal Change:** No change in *temperature* of system. Takes place slowly, allowing *sufficient time* for flow of thermal energy ($\Delta U = 0 \therefore +\Delta Q = +\Delta W$).
- Isochoric Change:** No change in *volume* of system. No net work is therefore done on or by the system ($\Delta W = 0 \therefore +\Delta Q = +\Delta U$).
- Isobaric Change:** No change in *pressure* of system.

Engineering Physics 3 [Thermodynamics : Theoretical Heat Engines]

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1. **Heat Engine Definition:** Heat engines extract work from a system when thermal energy flows from a hot space to a cold space along the thermal gradient [i.e. they convert thermal energy into useful work].
2. **Carnot Cycle:** Provides the *maximum* theoretical efficiency of a *reversible* engine. Maximum efficiency depends upon the cold-space to hot-space ratio.
3. **Carnot Indicator Diagram:** Isothermal compression (Q_{out}) → Adiabatic compression → Isothermal expansion (Q_{in}) → Adiabatic expansion.
4. **Otto Cycle:** Idealised petrol engine in which the same air is taken continuously through a cycle. Maximum efficiency depends upon compression and specific heat ratios.
5. **Otto Indicator Diagram:** Adiabatic compression → Isochoric heating → Adiabatic expansion → Isochoric cooling.
6. **Diesel Cycle:** Idealised diesel engine in which the same air is taken continuously through a cycle. Maximum efficiency depends upon compression, specific heat *and* cutoff ratios.
7. **Diesel Indicator Diagram:** Adiabatic compression → Isobaric expansion → Adiabatic expansion → Isochoric cooling.

Engineering Physics 4 [Thermodynamics : Practical Heat Engines]

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1. **No Adiabats:** Compression and expansion do not take place fast enough to avoid heat losses from system.
2. **No Isochor(s):** Cooling [and heating] does not take place at constant volume as the pistons are moving continuously.
3. **No Isobar [for diesel]:** Heating does not take place at constant pressure as the rate of combustion of fuel cannot be completely controlled.
4. **Corners rounded** because inlet/exhaust valves are needed and take a finite time to open and close.
5. **Maximum temperature** not realised due to imperfect combustion of fuel and incomplete scavenging of combustion products from cylinder (which also increases friction [and hence friction power] between cylinder and piston due to viscous residue).
6. **Indicated area of main loop smaller** (see all of above) so less work is done per cycle, reducing efficiency.
7. **Pumping Loop:** Pumping loop required (\approx atmospheric pressure) for induction and exhaust because real engines cannot take same fluid continuously through cycle (area of pumping loop subtracted from main loop, further reducing efficiency).

Engineering Physics 5 [Thermodynamics : Four Stroke Engine]

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1. **Induction Stroke:** Inlet valve opens; piston moves down cylinder; pressure differential draws in air+fuel mix (for petrol) or just air (for diesel – fuel is injected when air temperature has increased dramatically ($\approx 550^\circ\text{C}$) during compression).
2. **Compression Stroke:** Inlet valve closes; piston moves up cylinder; fuel+air mixture ignites near end of stroke; sudden increase in temperature and pressure.
3. **Expansion Stroke:** High pressure forces piston down cylinder; work is done on piston by expanding gas (hence 'power stroke'); work transferred to output shaft via connecting rod.
4. **Exhaust Stroke:** Exhaust valve opens; pressure differential expels combustion products.
5. **Ignition Process:** Fuel+air mixture is ignited with a spark in a petrol engine but simply through high temperature in a diesel engine.
6. **Ignition Timing:** The fuel+air mixture is ignited just before the end of the compression stroke to ensure combustion is ongoing for whole of expansion stroke, maximising pressure (and hence work done) on descending piston.
7. **Additional Key Engine Components:** Camshaft; spark plug; induction coil; electronic control unit (ECU); coolant; sump; bearings; oil; crankshaft; turbocharger+impeller.

Engineering Physics 6 [Thermodynamics : Engine Efficiency]

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1. **Input Power:** Calorific power delivered to engine by flow of fuel.
2. **Indicated Power:** The maximum theoretical power developed by expanding gas in cylinders [ALERT: check number of cylinders and divide engine frequency by two (as each four-stroke cycle requires two output shaft revolutions)]
3. **Friction Power:** The power lost between cylinder and output shaft due to: friction between piston and cylinder; power used to drive valve gear and pumps (oil/coolant/fuel injection); power used in induction and exhaust strokes.
4. **Brake (Output) Power:** The power delivered to the output (crank)shaft. [Indicated Power – Friction Power or $\tau\omega$]

5. **Thermal Efficiency:**
$$\varepsilon = \frac{P_{\text{indicated}}}{P_{\text{input}}} \quad [\approx 30\text{-}40\%]$$

6. **Mechanical Efficiency:**
$$\eta = \frac{P_{\text{output}}}{P_{\text{indicated}}} \quad [\approx 80\text{-}95\%]$$

7. **Overall Efficiency:**
$$\text{Overall Efficiency} = (\varepsilon)(\eta) = \frac{P_{\text{output}}}{P_{\text{input}}} \quad [\approx 30\text{-}35\%]$$

Engineering Physics 7 [Thermodynamics : Reversed Heat Engines]

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1. **Reversed Heat Engine Definition:** Reversed heat engines do work on a system, causing thermal energy to flow from a cold space to a hot space against the thermal gradient.
2. **Heat pumps and refrigerators** are identical in principle, differing only in their intended use.
3. **Heat Pump Definition:** Heat pumps heat a hot space by doing work on a system, causing thermal energy to flow from a cold space (such as the ground or a lake) to the hot space (such as a house) against the thermal gradient.
4. **Refrigerator Definition:** Refrigerators cool a cold space by doing work on a system, causing thermal energy to flow from a cold space (inside the refrigerator) to a hot space against (outside the refrigerator) the thermal gradient.
5. **Key Design Elements:** Compressor; evaporator; throttle valve; condenser.
6. **Heat pumps** are cheaper to run than conventional electric or gas heaters because more energy is 'pumped' into the hot space than is used to drive the compressor.
7. **Coefficient of Performance:**
$$COP_{hp} = COP_{ref} + 1$$