MECHANICAL ENGINEERING SCIENCE (UE25ME141A/B)

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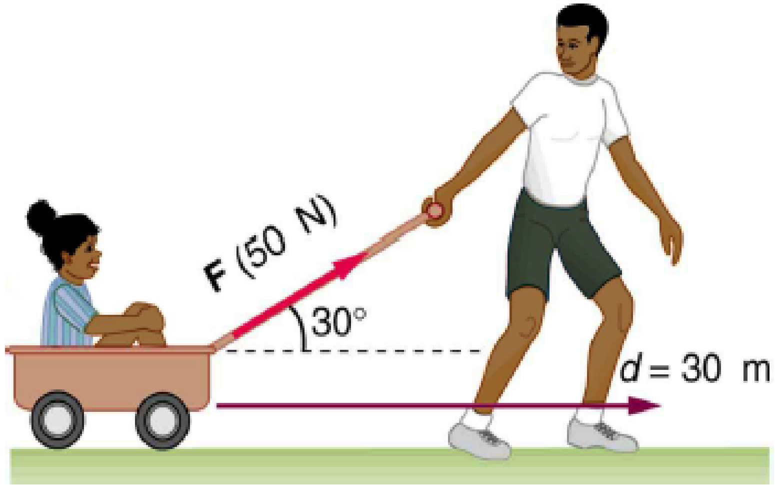
Work

From engineering mechanics point of view, work is said to be done when the point of application of a force moves through a certain distance.

The amount of work done is evaluated as the product of the force applied and the distance moved.

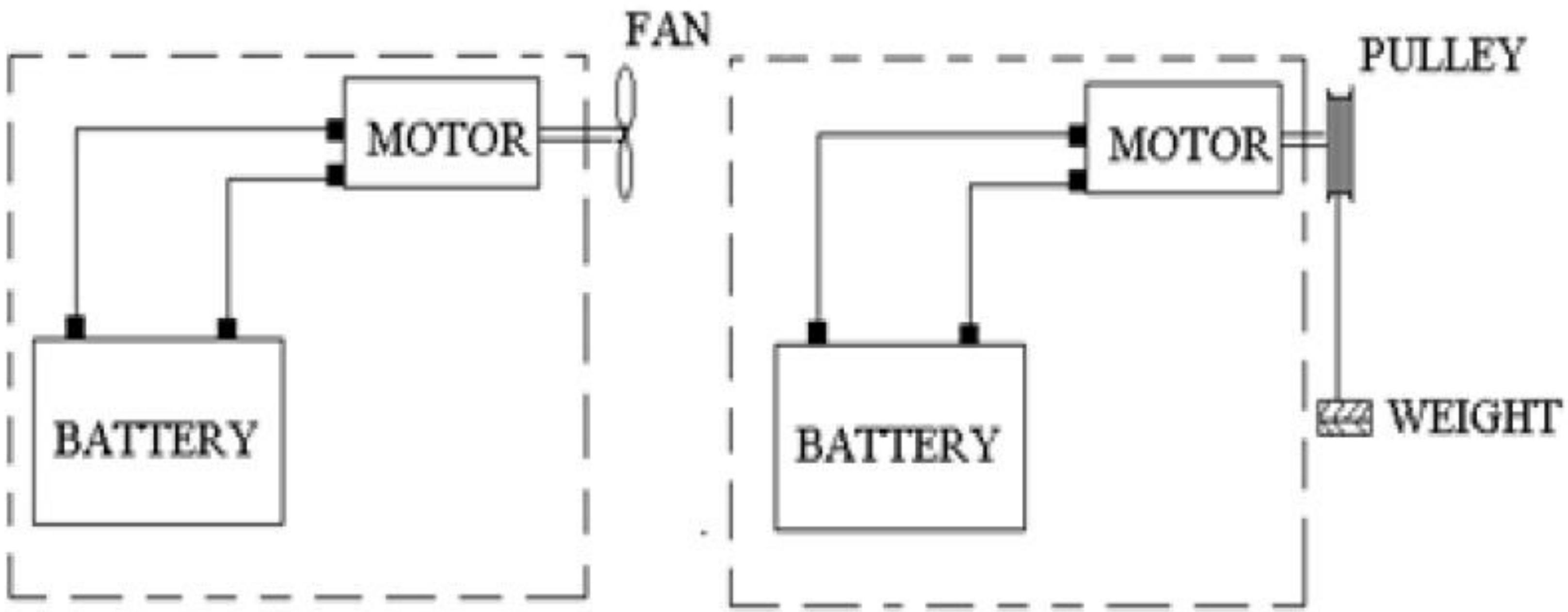


$$\mathrm{W} = \text{Force} \times \text{distance}$$
$$= 50 \text{ Cos } 30^0 \times 30$$
$$= 1299.04 \text{ N}$$

Work

The thermodynamic work described as "the energy transfer across the boundary when a system changes its state due to the movement of a part of the boundary under the action of a force"

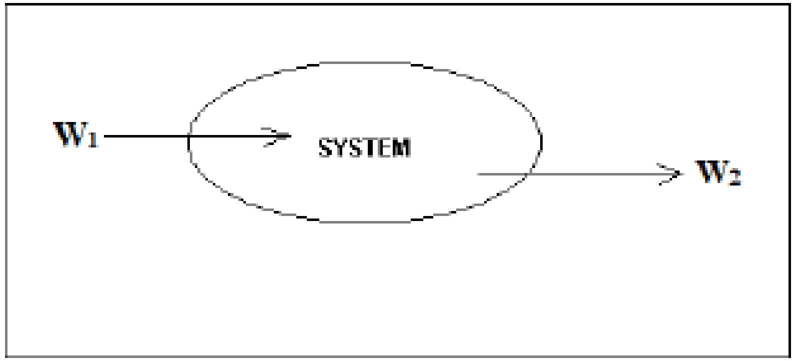
Illustration of Work



Sign Conventions of Work

Work done by the system is treated positive

Work done on the system is treated negative.

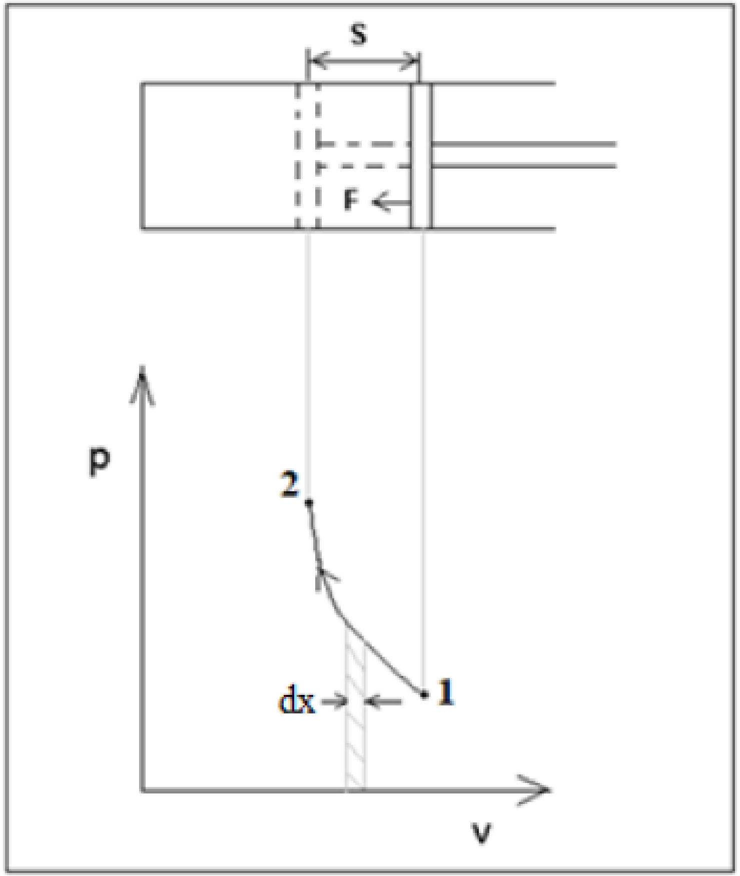


W_1 is -ve and W_2 is +ve

Units of work → joules(J), kilo joules(kJ)

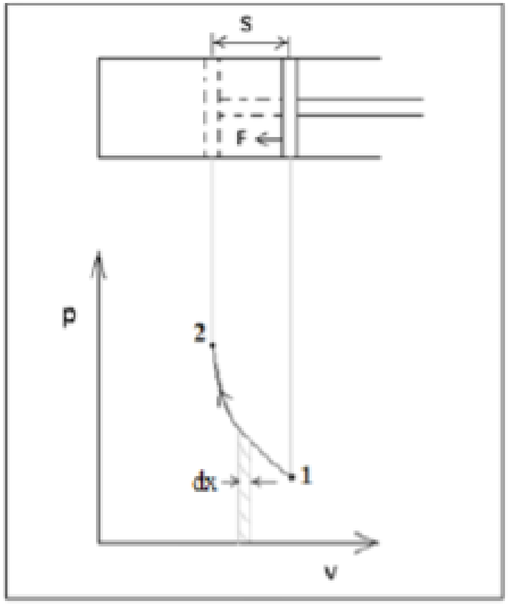
Sometimes work transferred/unit time is mentioned and the unit would be J/s or Watts (W).

Moving boundary or pdV work



Consider a fixed quantity of gas enclosed in a cylinder provided with a piston, as shown. Let the gas enclosed be treated as the system. Let it be compressed from initial state 1 to final state 2 by means of a quasi-static process.

Moving boundary or pdV work



Let F be the force applied and A be the cross sectional area of the piston. Let p be the pressure exerted on the gas.
Between the end states 1 and 2, consider a small displacement dx as indicated.
Let ∂W be the work done to achieve this small displacement.

Moving boundary or pdV work

We may write

$$\partial W = F \times dx$$

$$\partial W = (p \times A) \times dx$$

$$\partial W = p \times (A \times dx)$$

$$\partial W = p \times dV$$

To get the total work done between 1 and 2, we need to integrate: -

$$\int_1^2 \partial W = \int_1^2 p\, dV$$

$$W_{1-2} = \int_1^2 p\, dV$$

Moving boundary or pdV work

The expression $\int pdV$ can be integrated only if we know the relation between p and V.

When the relation between p and V is defined, the path followed gets defined. The path depends on the type of process.

Or, we can say that for different processes there are different paths.

Moving boundary or pdV work for Isothermal Process

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For an Isothermal Process

We have $P_1V_1 = P_2V_2 = PV = \text{Constant}$

Hence $P = \text{Constant}/V$

$$\text{Moving Boundary Work, } W = \int_1^2 P\,dV$$

$$= \int_1^2 \left(\frac{\text{Constant}}{V}\right) dV$$

$$= \text{Constant} \int_1^2 \left(\frac{dV}{V}\right)$$

$$= \text{Constant}\ \ln(V)_1^2$$

$$= P_1V_1 \ln\left(\frac{V_2}{V_1}\right)$$

Moving boundary or pdV work for Various processes

Sl. No	Process	Relation between P and V	Expression for pdV work
1	Isothermal process	PV = const. $P_1V_1 = P_2V_2$	$W = P_1V_1 \ln\left(\frac{V_2}{V_1}\right)$
2	Adiabatic process	PV^γ = constant $P_1V_1^\gamma = P_2V_2^\gamma$	$W = \frac{p_1V_1 - p_2V_2}{\gamma - 1}$
3	Polytropic process	PV^n = const $P_1V_1^n = P_2V_2^n$	$W = \frac{p_1V_1 - p_2V_2}{n - 1}$
4	Isochoric process	V =constant. dV = O $P_1/P_2 = T_1/T_2$ (Kelvin)	W = O
5	Isobaric process	P = constant. dP = O $V_1/T_1 = V_2/T_2$	$W = P\,(V_2 - V_1)$

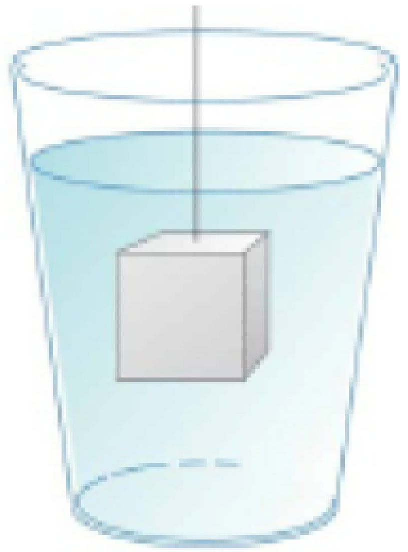
Other forms of Work

Sl. No	Type of Work Transfer	Expression for work
1	Shaft Work	• $W = \text{Torque} \times \text{Angular Displacement}$ $W = T \times 2\pi$, Joules per rotation • $W = T \times 2\pi \times n$, Joules for n rotations • Work done per second $=$ $\dot{W} = \frac{T \times 2\pi N}{60}$, Joules per second, where N = number of rotations per minute (rpm)

Other forms of Work

Sl. No	Type of Work Transfer	Expression for work
2	Electric Work	W = Voltage * Current
3	Surface Tension Work	W = Surface Tension * Area = σ*A
4	Work done in stretching a wire	$W = -\frac{AEL}{2}(\varepsilon_2^2 - \epsilon_1^2)$ where A = cross sectional area E = Young's Modulus L = Length of the specimen ε = Linear Strain
5	Flow Work	W= pressure*volume

HEAT is defined as a form of energy in transition taking place due to a difference in temperature.



Consider a hot copper block and a beaker of cold water.

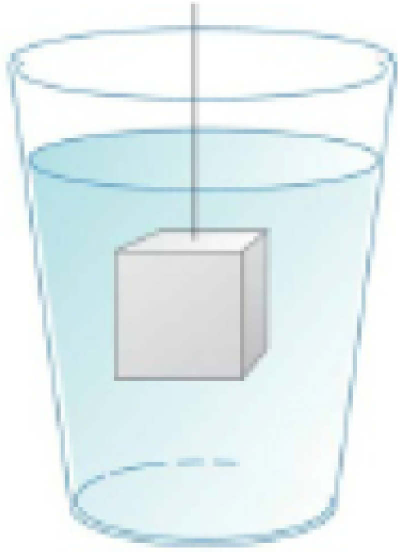
Let the hot block be immersed in cold-water.

On immersion, we note that there is a transfer of energy from the block to the cold water.

The transfer of energy is happening due to a difference in temperature between the block and the water.

This form of energy transfer is referred to as heat or heat transfer.

Heat



Heat is transferred only till there is a temperature difference.

Once equality of temperature has been attained, there is no heat or heat transfer.

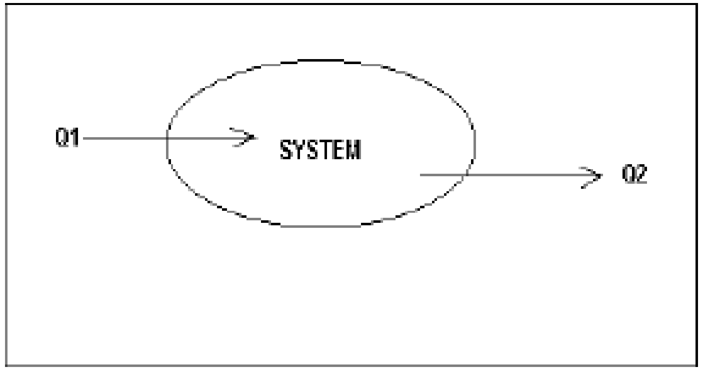
From this we conclude that systems do not possess heat, they only possess energy.

Heat is a transient phenomena, which can be observed at the system boundary.

Sign Convention for Heat

Heat added to a system is treated +ve

Heat removed from a system is treated as –ve.



Q1 is +ve

Q2 is –ve

Units of heat → joules(J), kilo joules(kJ)

Sometimes heat transferred/unit time is mentioned and the unit would be J/s or Watts(W).

Comparison between Work and Heat

Systems do not possess heat or work, they only possess energy.

Transient phenomena: Heat and Work are observed only there is transfer of energy and hence are transient in nature.

Boundary phenomena: Both heat and work are observed at the system boundary. On change of the system boundary the form of energy transfer may change from heat to work or vice versa.

Path functions: Both heat and work are path functions and hence inexact differentials.

Comparison between Work and Heat – Sign Convention

Heat:

Heat added to the system is +ve

Heat removed from the system is –ve.

Work:

Work done by the system is +ve

Work done on the system is –ve

THANK YOU

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