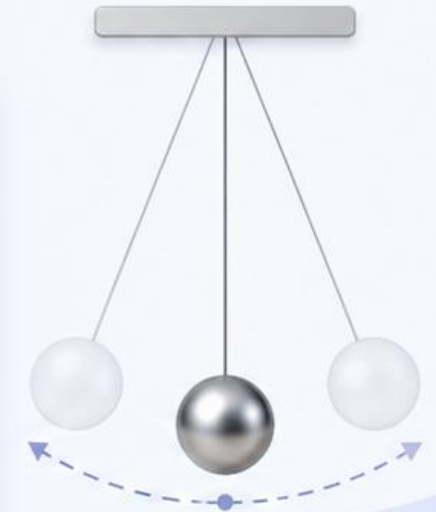
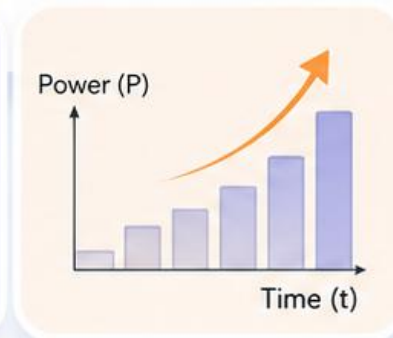
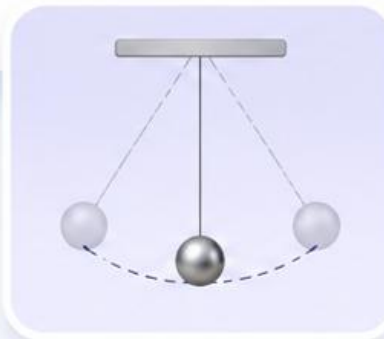
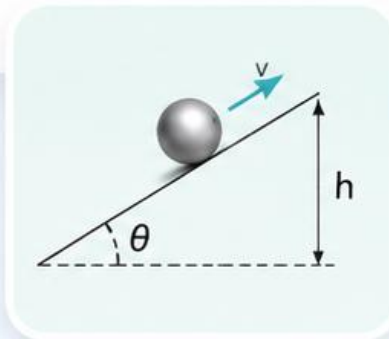
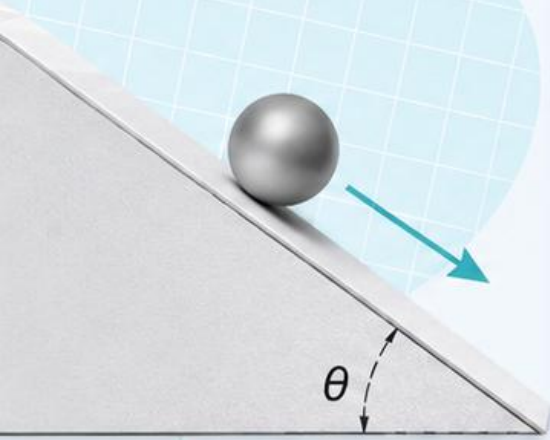


Chapter 5

Work, Energy and Power

Work • Energy • Power



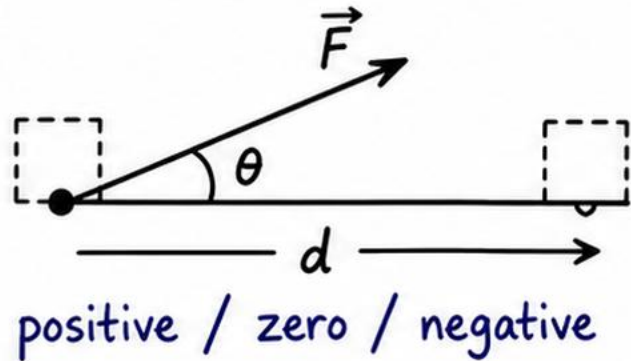
WORK, ENERGY & POWER

Physics gives work, energy and power precise meanings—and links them through motion.

① WORK

Energy transferred by a force acting through displacement.

$$W = F \cdot d = Fd \cos \theta$$

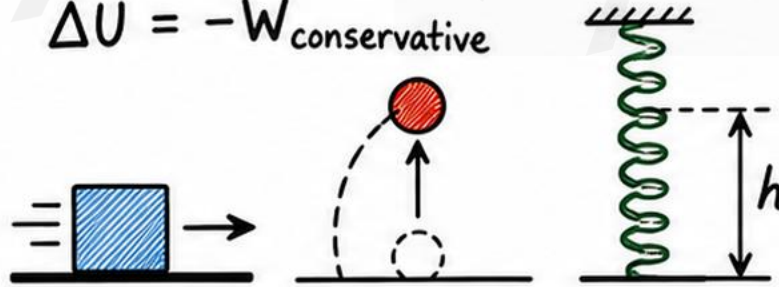


② ENERGY

Kinetic energy belongs to motion; potential energy belongs to position or configuration.

$$K = \frac{1}{2}mv^2$$

$$\Delta U = -W_{\text{conservative}}$$



③ POWER

Rate of doing work or transferring energy.

$$P_{\text{avg}} = \frac{W}{\Delta t}$$

$$P = \frac{dW}{dt} = F \cdot v$$



NET WORK $\rightarrow$ CHANGE IN KINETIC ENERGY $\rightarrow$ ENERGY ACCOUNTING $\rightarrow$ POWER

$$W_{\text{net}} = \Delta K$$

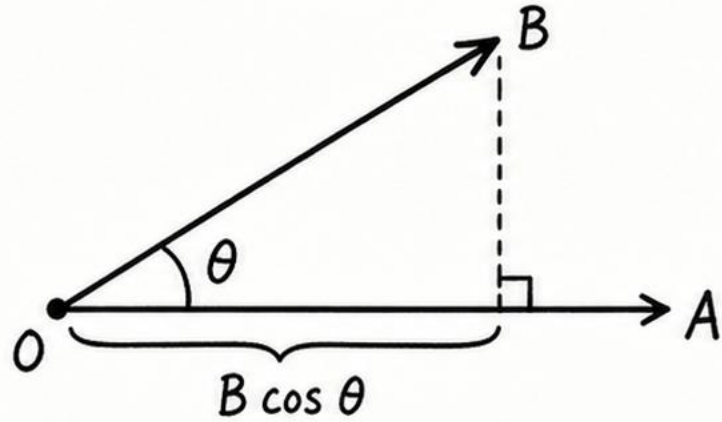
$$\Delta(K + U) = W_{\text{non-conservative}}$$

SCALAR PRODUCT — FOUNDATIONS

① DEFINITION & GEOMETRY

The scalar (dot) product of two vectors is a scalar.

$$A \cdot B = AB \cos \theta$$



$$A \cdot B = A(B \cos \theta)$$

② ALGEBRA

$$A \cdot B = B \cdot A$$

$$A \cdot (B + C) = A \cdot B + A \cdot C$$

$$A \cdot (\lambda B) = \lambda(A \cdot B)$$

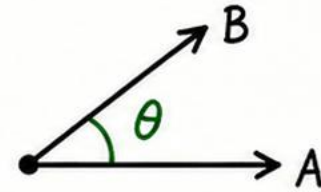
$$A \cdot B = A_x B_x + A_y B_y + A_z B_z$$

$$A^2 = A \cdot A = A_x^2 + A_y^2 + A_z^2$$

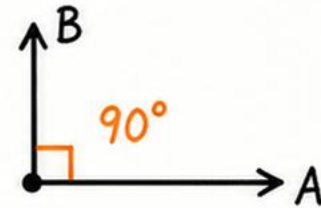
③ UNIT VECTORS & SIGN

$$\hat{i} \cdot \hat{i} = \hat{j} \cdot \hat{j} = \hat{k} \cdot \hat{k} = 1$$

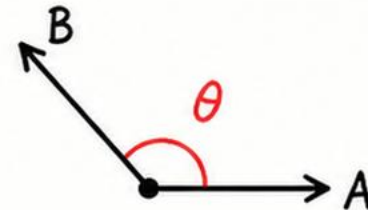
$$\hat{i} \cdot \hat{j} = \hat{j} \cdot \hat{k} = \hat{k} \cdot \hat{i} = 0$$



acute: $A \cdot B > 0$



right angle: $A \cdot B = 0$



obtuse: $A \cdot B < 0$

Dot product = magnitude of one vector $\times$ component of the other along it.

WORKED EXAMPLE — FORCE-DISPLACEMENT ANGLE

GIVEN — $F = (3\hat{i} + 4\hat{j} - 5\hat{k}) \text{ N}$
 $d = (5\hat{i} + 4\hat{j} + 3\hat{k}) \text{ m}$

REQUIRED — Angle θ between F and d ; projection of F on d .

PRINCIPLE / FORMULA — $F \cdot d = |F||d| \cos \theta$
scalar projection of F on $d = \frac{F \cdot d}{|d|}$

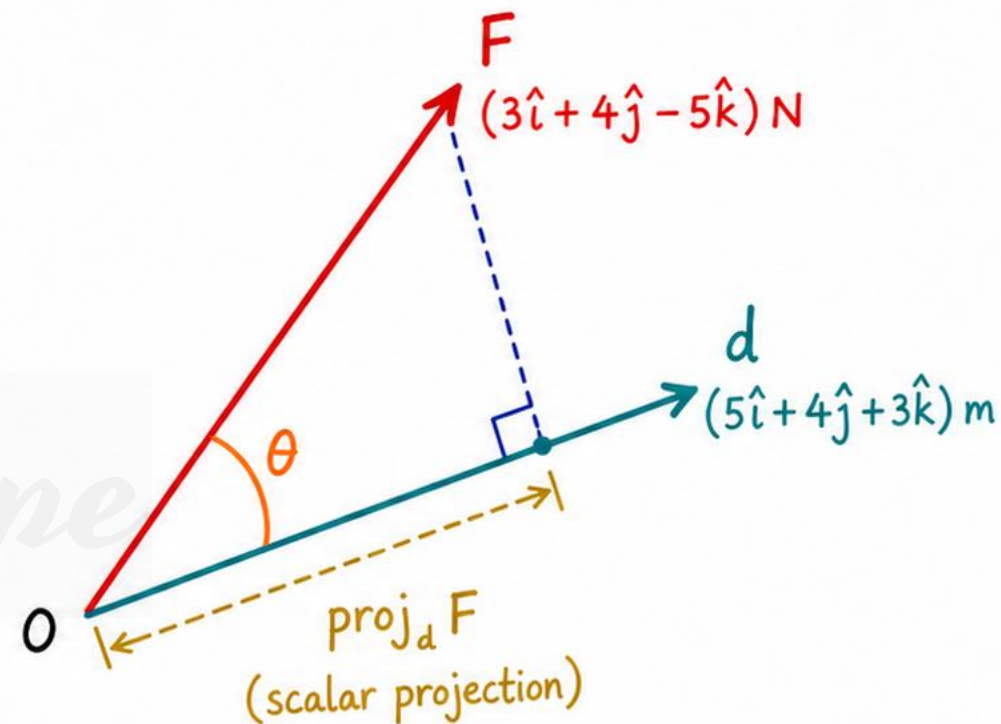
UNIT CONVERSION — None; components are already in SI.

SUBSTITUTION — $F \cdot d = 3(5) + 4(4) + (-5)(3)$
 $|F| = |d| = \sqrt{25 + 16 + 9} = \sqrt{50}$

CALCULATION — $F \cdot d = 16 \text{ J}$
 $\cos \theta = \frac{16}{50} = 0.32$
 $\theta = \cos^{-1}(0.32) = 71.3^\circ$
 $\text{proj}_d F = \frac{16}{\sqrt{50}} = 2.26 \text{ N}$

FINAL ANSWER — $\theta = 71.3^\circ$; scalar projection = 2.26 N

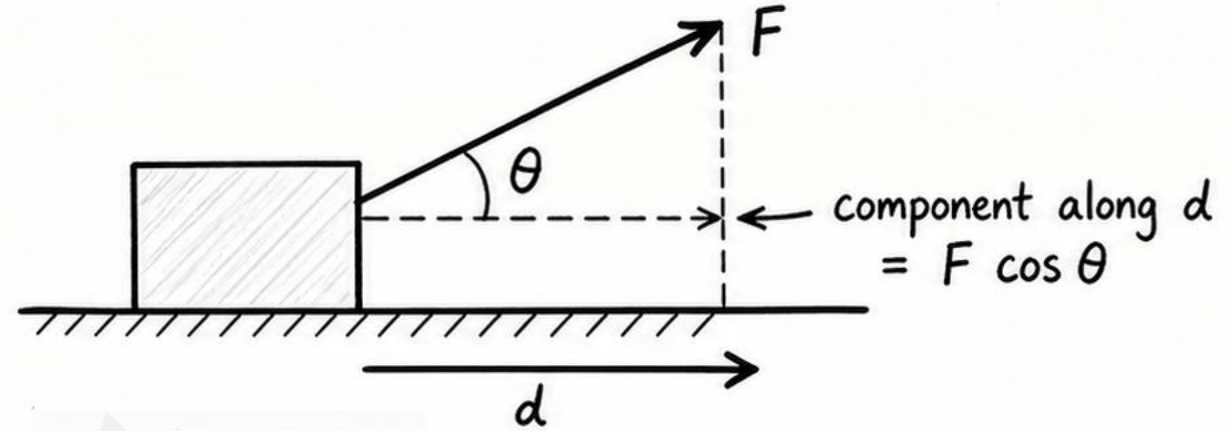
QUICK CHECK — $0 < F \cdot d$, so θ must be acute. Vector projection = $\left(\frac{F \cdot d}{d^2}\right)d = 0.32d$.



WORK BY A CONSTANT FORCE

Work by a specified force equals the component of that force along the displacement times the displacement.

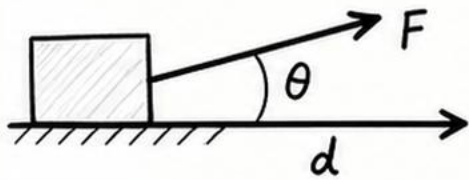
$$W = F \cdot d = Fd \cos \theta$$



POSITIVE WORK

$$0^\circ \leq \theta < 90^\circ$$

$$W > 0$$

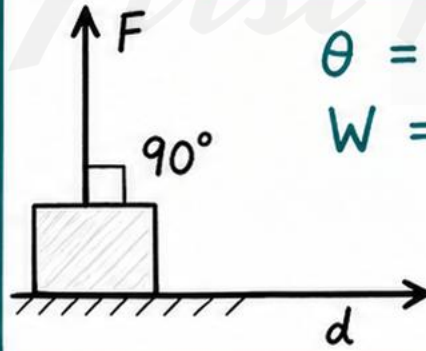


force generally
along motion.

ZERO WORK

$$\theta = 90^\circ$$

$$W = 0$$

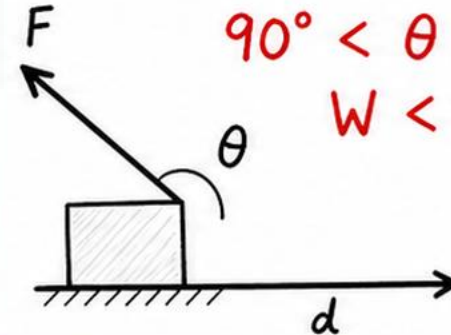


force
perpendicular
to motion.

NEGATIVE WORK

$$90^\circ < \theta \leq 180^\circ$$

$$W < 0$$



force generally
opposite to
motion.

NO WORK WHEN

- displacement is zero
- the specified force is zero
- force is perpendicular to displacement.

SI unit: joule (J) = N m

$$[W] = M L^2 T^{-2}$$



Always name the force, the body, and the displacement. Action-reaction forces need not do equal and opposite work.



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