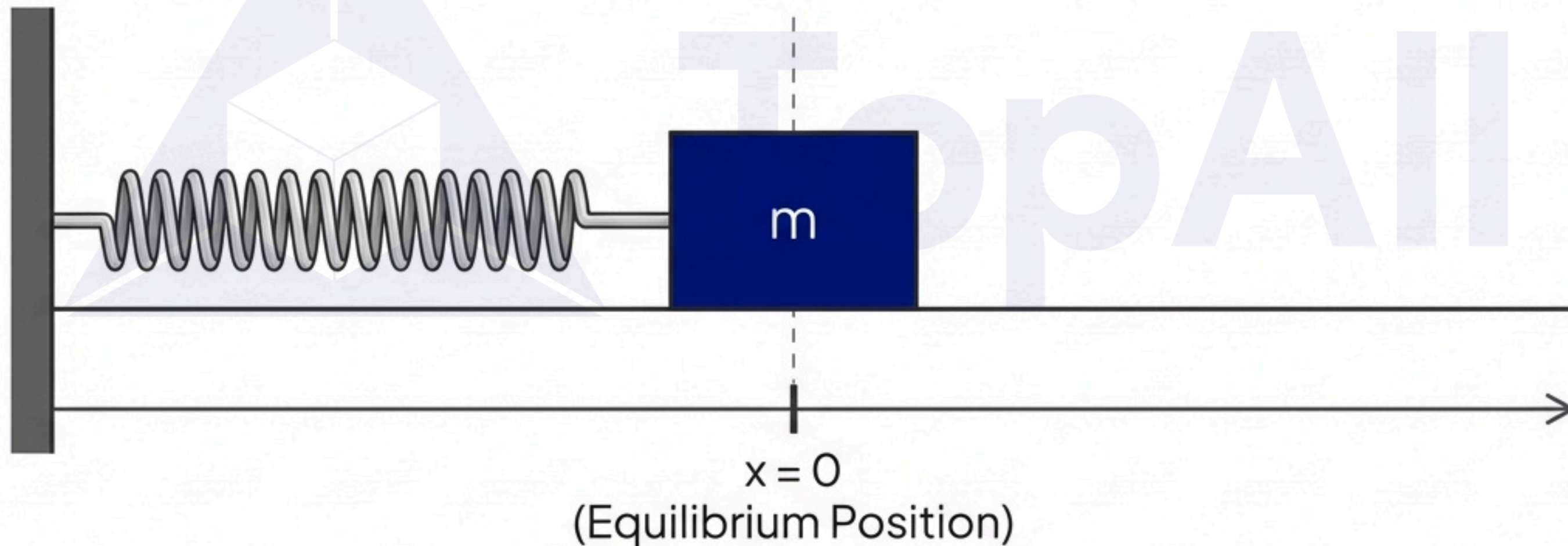


Potential Energy of a Spring

Mechanics of Restoring Forces and Energy Conservation

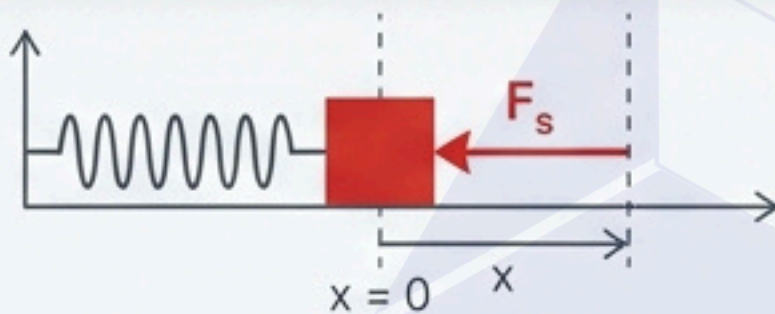


Spring Force and Hooke's Law

For an ideal, massless spring on a frictionless surface, the force it exerts is directly proportional to its displacement from equilibrium.

F_s (Spring Force)

A variable, conservative **restoring** force.



$$F_s = -kx$$

k (Spring Constant)

Defines the stiffness of the spring. Large k = Stiff; Small k = Soft.

SI UNIT: N m^{-1}

DIMENSIONS: $[\text{M T}^{-2}]$

- (Negative Sign)

Indicates the force always **opposes** the direction of displacement.

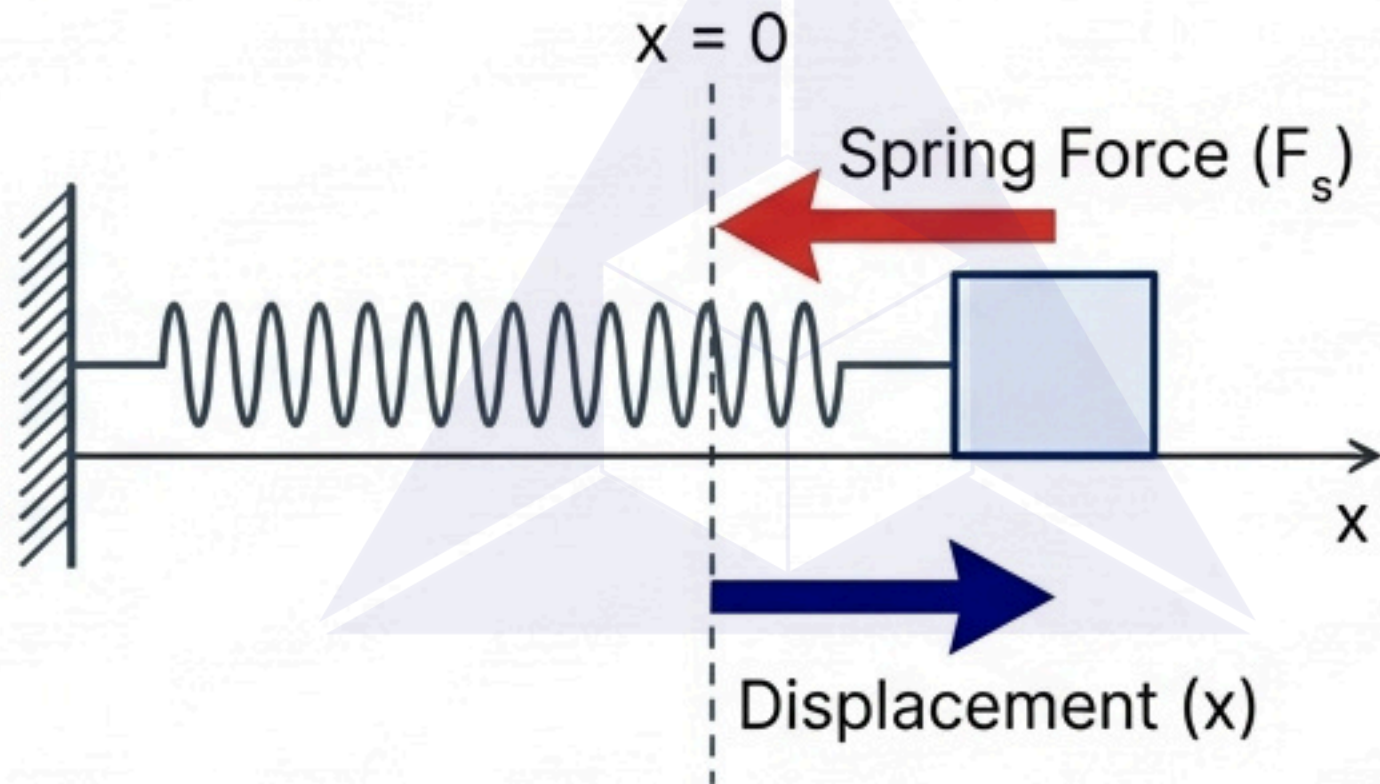
x (Displacement)

Distance of the block from the equilibrium position ($x = 0$).

The Restoring Nature of Spring Force

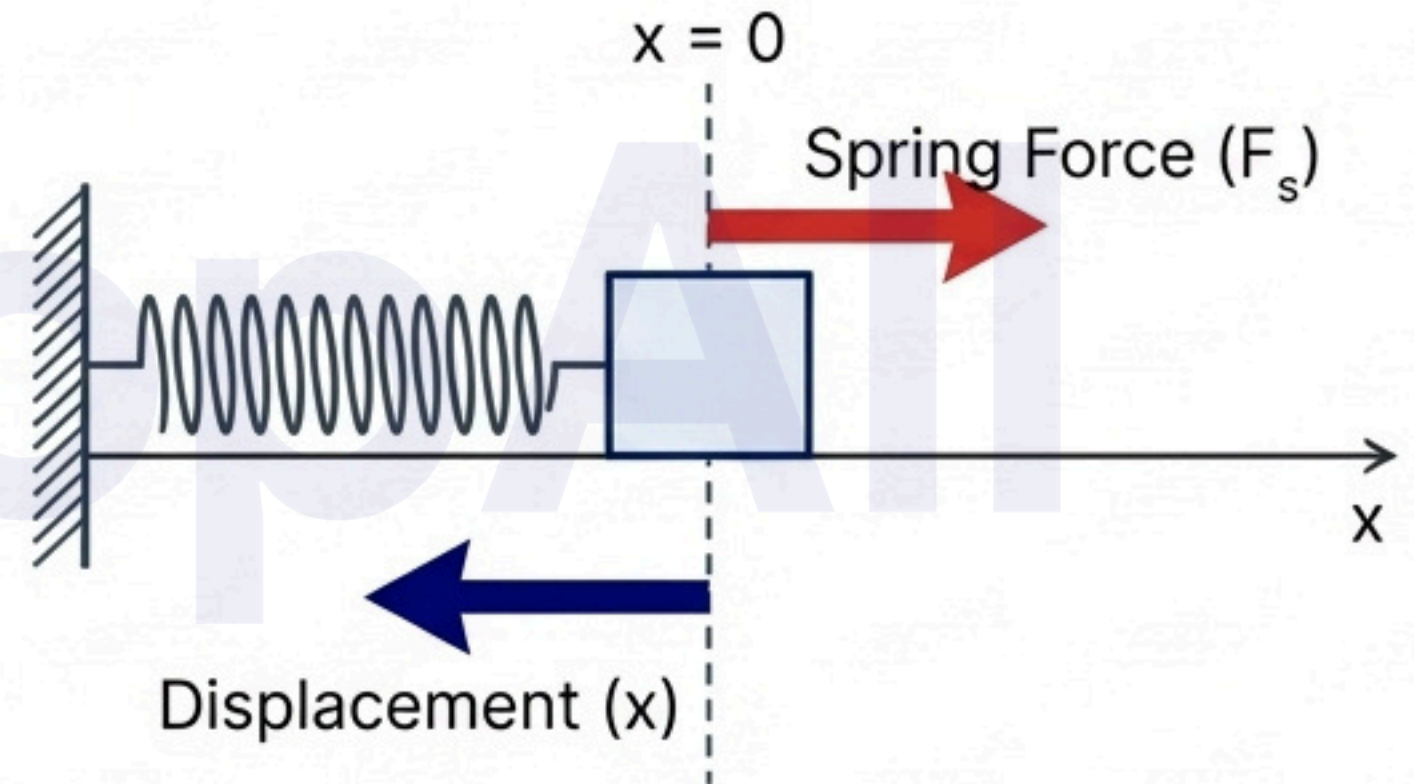
The spring force F_s always acts to return the system to its un-stretched equilibrium state ($x = 0$).

Extension ($x > 0$)



x is Positive $\rightarrow F_s$ is Negative

Compression ($x < 0$)

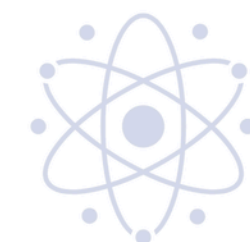


x is Negative $\rightarrow F_s$ is Positive



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$$E=mc^2$$



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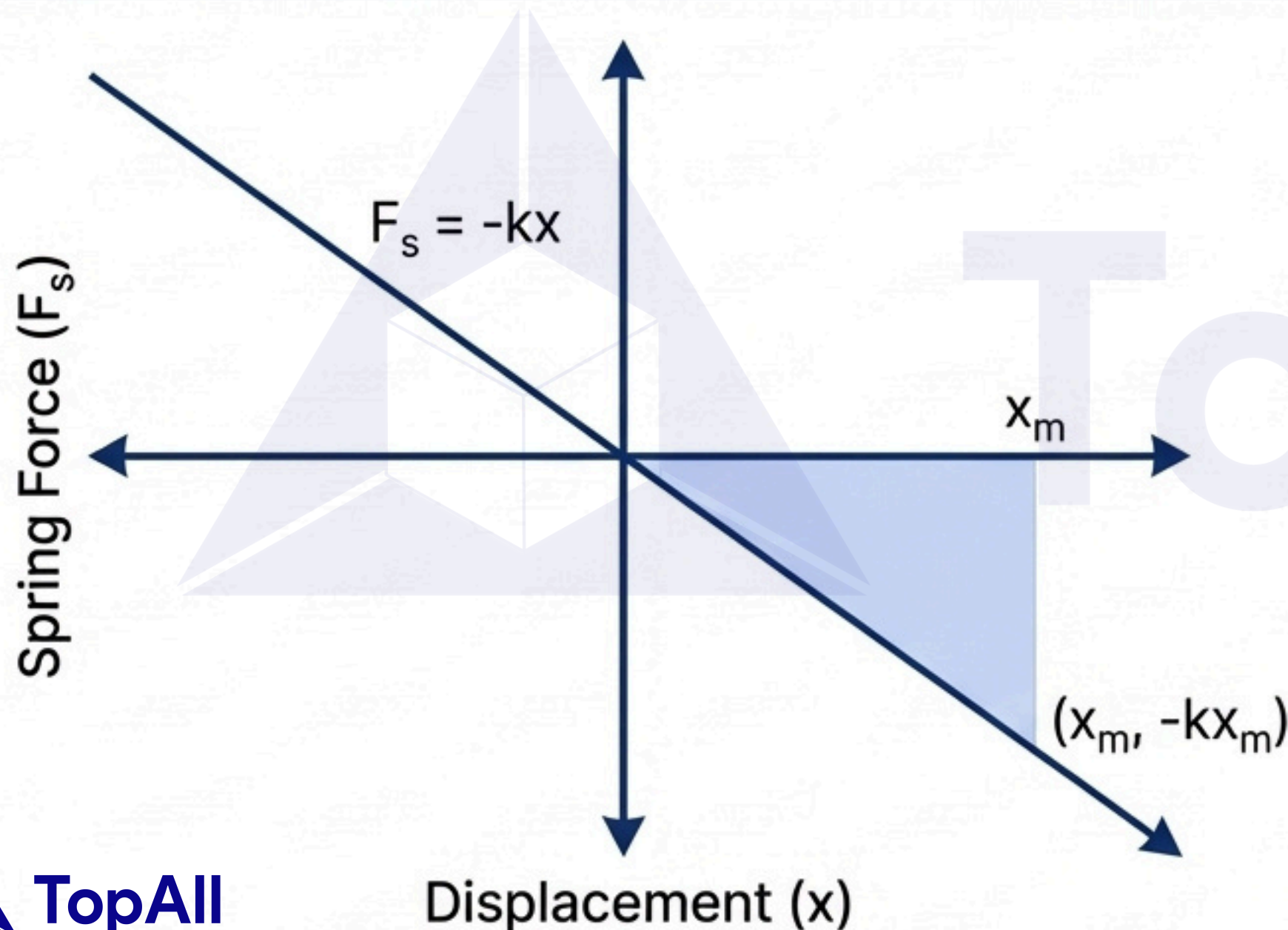
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Force-Displacement Graph & Work

The work done by the **variable spring force** is exactly equal to the area under the F_s versus x curve.



Work Done by Spring (W_s)

Area of the shaded triangle.

$$W_s = \frac{1}{2} \times \text{base} \times \text{height}$$

$$W_s = \frac{1}{2} (x_m) (-kx_m)$$

$$W_s = -\frac{1}{2} k x_m^2$$

(Negative because force opposes motion)

Work Done by External Force (W)

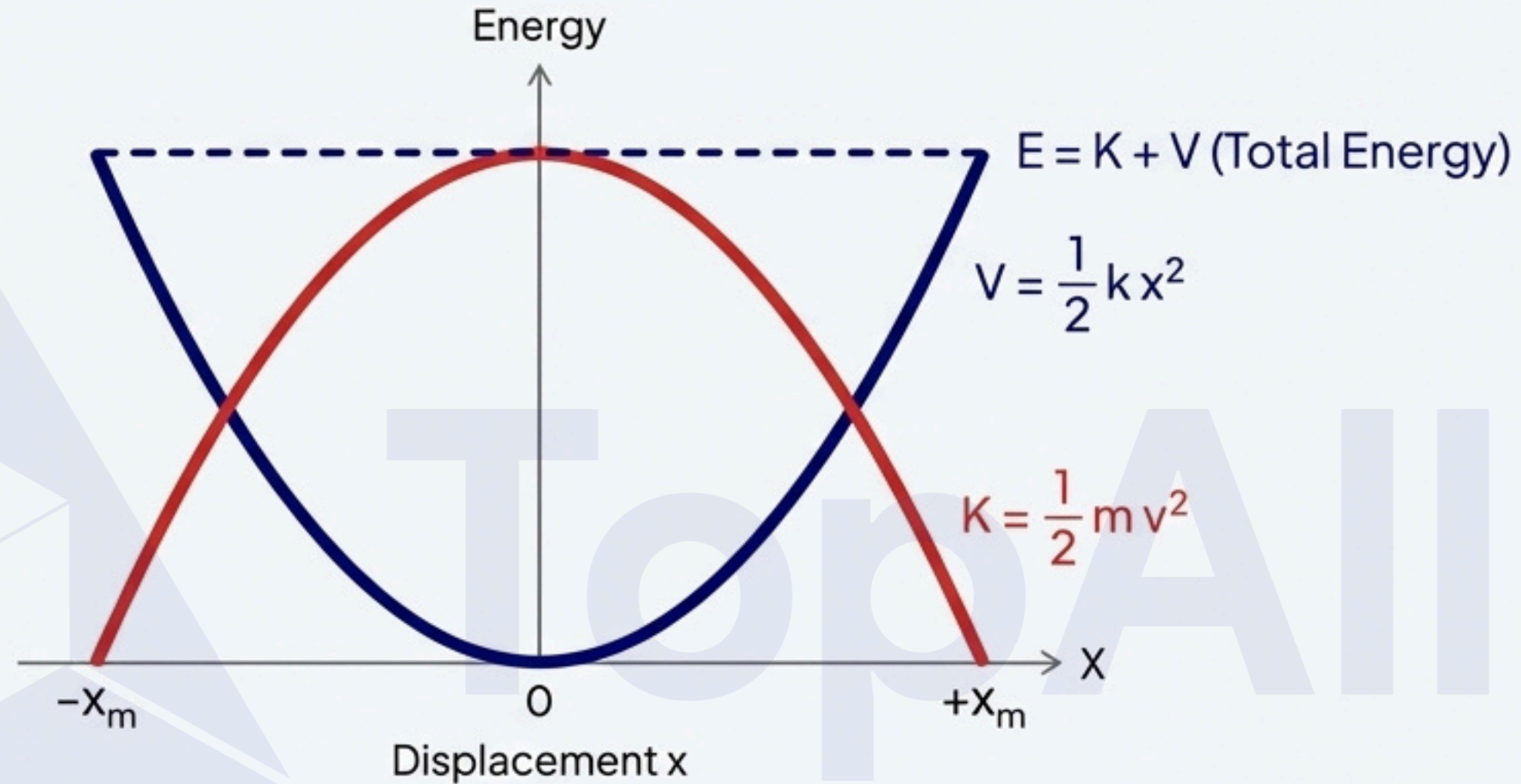
Overcomes the spring force.

$$W = +\frac{1}{2} k x_m^2$$

Spring Potential Energy & Conservation

The work done against the spring is stored as Elastic Potential Energy $V(x)$.

Total mechanical energy remains constant.



KEY MATHEMATICAL SYNTHESIS

$$\frac{1}{2} m v^2 + \frac{1}{2} k x^2 = \frac{1}{2} k x_m^2$$

Maximum Velocity (at $x=0$):

$$v_m = \sqrt{\frac{k}{m}} \cdot x_m$$

Key Exam Takeaways

High-yield concepts and proofs for solving mechanical energy problems.

Conservative Force Proof

The work done by the spring force in a closed, cyclic process (e.g., from x_i back to x_i) is exactly zero.

Path Independence

Work done depends only on initial and final positions: $W_s = \frac{1}{2} kx_i^2 - \frac{1}{2} kx_f^2$

Derivative Relationship

Spring force is the negative spatial derivative of potential energy: $F_s = -\frac{dV}{dx}$

Energy States

A At $x = 0$:
Potential Energy is ZERO.
Kinetic Energy is MAX.

B At $x = \pm x_m$:
Kinetic Energy is ZERO.
Potential Energy is MAX.

Dimensional Symmetry

Spring constant k/m has the dimensions of $[T^{-2}]$, ensuring kinematic formulas remain dimensionally consistent.



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