Work, Power, and Energy

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Formula Name / Topic	Formula	Condition / Notes
1. Work Done (Constant Force)	$W = \vec{F} \cdot \vec{S} = FS\cos\theta$	Force $\vec{F}$ is constant. θ is angle between $\vec{F}$ and displacement $\vec{S}$.
2. Work Done (Variable Force)	$W = \int_{x_1}^{x_2} F_x dx$	Force varies with position.
	$W = \int \vec{F} \cdot d\vec{r}$	
3. Work from Graph	$W = \text{Area under } F\text{-}x \text{ graph}$	Area between force curve and displacement axis (Area above axis is +, below is -).
4. Kinetic Energy (KE)	$K = \frac{1}{2}mv^2 = \frac{p^2}{2m}$	$p = mv$ is linear momentum. Relation between KE and Momentum is crucial.
5. Work-Energy Theorem	$W_{\text{net}} = \Delta K = K_f - K_i$	Valid for **all** frames (inertial/non-inertial). W_{net} is work by ALL forces (conservative, non-conservative, pseudo).
6. Gravitational Potential Energy (PE)	$U = mgh$	Near Earth's surface where g is constant. Ref level at ground ($U = 0$).
7. Spring Potential Energy	$U = \frac{1}{2}kx^2$	x is elongation or compression from **natural length**. k is spring constant.
8. Conservative Force & PE Relation	$F = -\frac{dU}{dx}$	Only defined for conservative forces (Gravity, Electrostatic, Spring).
	$\Delta U = -W_{conservative}$	

9. Conservation of Mechanical Energy	$K_i + U_i = K_f + U_f$	Condition: Only conservative forces do work ($W_{ext} = 0, W_{nc} = 0$).
10. Work by Non-Conservative Forces	$W_{nc} = \Delta E_{mech} = (K_f + U_f) - (K_i + U_i)$	Used when friction or air resistance is present.
11. Average Power	$P_{avg} = \frac{\Delta W}{\Delta t}$	Total work done divided by total time taken.
12. Instantaneous Power	$P = \vec{F} \cdot \vec{v} = Fv \cos \theta$	Rate of work at a specific instant.
13. Vertical Circular Motion (Critical)	$v_{top} \geq \sqrt{gR}$, $v_{bottom} \geq \sqrt{5gR}$	Condition to complete a full vertical circle (String/Loop).
14. Vertical Circular Motion (Tension)	$T_{bottom} - T_{top} = 6mg$	Difference in tension between lowest and highest point.
15. Coefficient of Restitution (*e*)	$e = \frac{v_{sep}}{v_{app}} = \frac{v_2 - v_1}{u_1 - u_2}$	$e = 1$ (Elastic), $0 < e < 1$ (Inelastic), $e = 0$ (Perfectly Inelastic). Along Line of Impact.
16. Elastic Collision (1D)	$v_1 = \left(\frac{m_1 - m_2}{m_1 + m_2}\right) u_1 + \left(\frac{2m_2}{m_1 + m_2}\right) u_2$	Momentum and KE are conserved.
17. Perfectly Inelastic Collision	$V_{common} = \frac{m_1 u_1 + m_2 u_2}{m_1 + m_2}$	Bodies stick together ($e = 0$). Max loss of KE.
18. Loss in KE (Collision)	$\Delta K = \frac{1}{2} \frac{m_1 m_2}{m_1 + m_2} (u_1 - u_2)^2 (1 - e^2)$	General formula for KE loss in any head-on collision.
19. Equilibrium Conditions	Stable: $U'' > 0$, Unstable: $U'' < 0$, Neutral: $U'' = 0$	$U'' = d^2U/dx^2$. At equilibrium, Net Force is zero.
20. Chain Pulling Problem	$W = \frac{MgL}{2n^2}$	Work to pull a chain hanging $1/n$ th part off a table back onto the table.
21. Stopping Distance	$d_s = \frac{v^2}{2\mu g}$	Vehicle stopping distance with friction coefficient μ.

22. Power of a Pump/Motor	$P = \frac{dm}{dt}gh + \frac{1}{2}\frac{dm}{dt}v^2$	Power to lift water rate dm/dt to height h and eject with velocity v.
23. Rebound Height	$h_n = e^{2n}h_0$	Height after n^{th} bounce. Total distance $= h_0\left(\frac{1+e^2}{1-e^2}\right)$.
24. Spring-Block (Sudden Release)	$x_{max} = \frac{2mg}{k}$	If a block of mass m attached to a spring is released suddenly from natural length.
25. Bullet Penetration	$F_{avg} \cdot d = \frac{1}{2}mv^2$	Work done by resistive force = Change in KE.
26. Oblique Collision	$v\sin\alpha = u\sin\theta$	Comp. of velocity $\perp$ to line of impact is unchanged. Along line of impact, use e.