After this video you can:

- discuss what is meant by a conservation law.
- discuss energy and its various forms.
- calculate work done in any constant force scenario.
- calculate power supplied by a constant force.

momentum

angular momentum

Energy – capacity to do work

work – transfer of energy

Conservation Law

↳ $E_{before} = E_{after}$ ⇒ before/after some interaction of matter

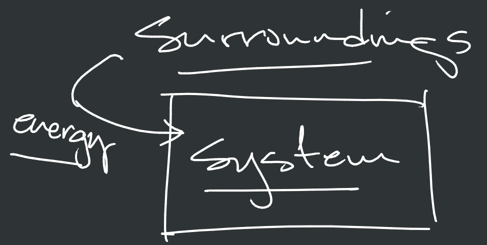
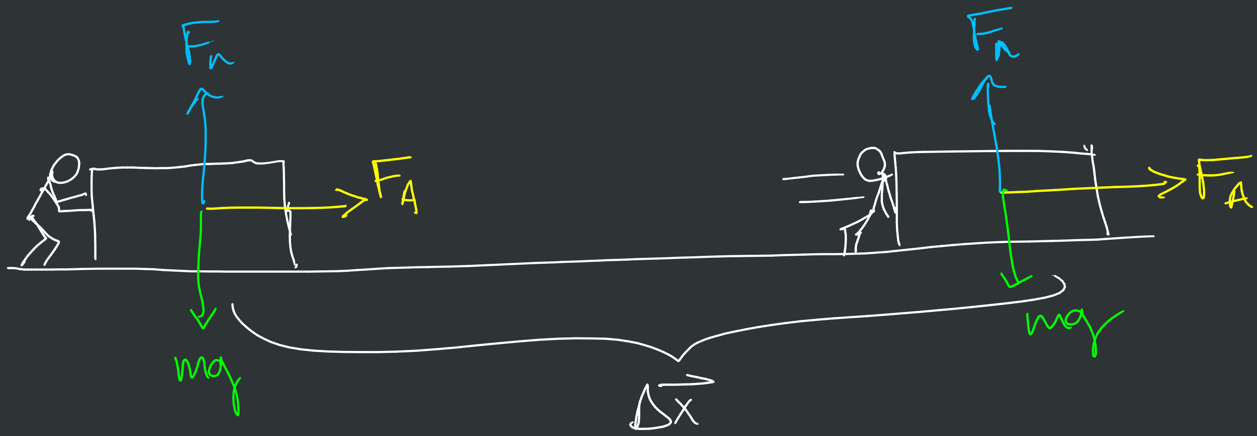


Table 6.1 Some Common Forms of Energy

Form of Energy	Brief Description
Translational kinetic	Energy of translational motion (Chapter 6)
Elastic	Energy stored in a "springy" object or material when it is deformed (Chapter 6)
Gravitational	Energy of gravitational interactions (Chapter 6)
Rotational kinetic	Energy of rotational motion (Chapter 8)
Vibrational, acoustic, seismic	Energy of the oscillatory motions of atoms and molecules in a substance caused by a mechanical wave passing through it (Chapters 11 and 12)
Internal	Energies of motion and interaction of atoms and molecules in solids, liquids, and gases, related to our sensation of temperature (Chapters 13–15)
Electromagnetic	Energy of interaction of electric charges and currents; energy of electromagnetic fields, including electromagnetic waves such as light (Chapters 14, 17–22)
Rest	The total energy of a particle of mass m when it is at rest, given by Einstein's famous equation $E = mc^2$ (Chapters 26, 29, and 30)
Chemical	Energies of motion and interaction of electrons in atoms and molecules (Chapter 28)
Nuclear	Energies of motion and interaction of protons and neutrons in atomic nuclei (Chapters 29 and 30)

Work - energy transfer when a force acts on an object that moves

- only the component of force in the direction of displacement



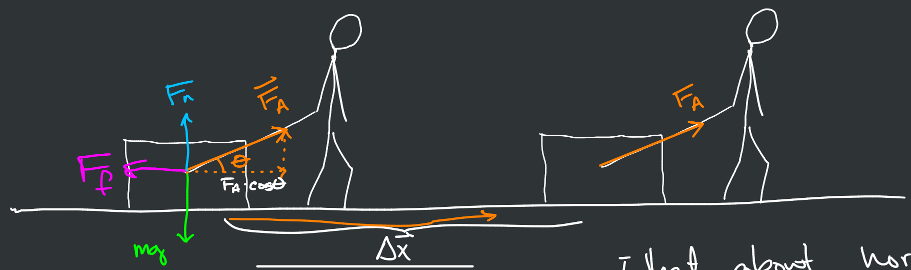
$$Work = F_A \cdot \Delta x$$

$$[N] \cdot [m]$$

$$\left[\frac{kg\,m}{s^2}\right] \cdot [m]$$

$$\underbrace{\left[\frac{kg\,m^2}{s^2}\right]}$$

[Joule] [J]



$$W = F_A \cdot \cos\theta \cdot \Delta x$$

What about normal or weight

$$W_{F_n} = F_n \cdot \cos\theta \cdot \Delta x$$

angle between F_n and Δx

$\theta = 90°$

$\cos 90° = 0$

$W_{F_n} = 0$

$$\boxed{W = |F|\,|\Delta x| \cdot \cos\theta}$$

>0 $\quad 0<\theta<90°$

<0 $\quad 90<\theta<180$

[calorie]

Work > 0 ← energy transfer to system

Work < 0 ← energy transfer out

Power - rate that work is done

$$\boxed{\underline{\text{Power}} = \frac{W}{\Delta t}}$$

$$P = \frac{|F||\Delta x|\cos\theta}{\Delta t}$$

velocity

$$\boxed{P = F \cdot v \cdot \cos\theta}$$

b/t F + V

constant velocity

$$\frac{[\text{Joules}]}{[\text{seconds}]} = \frac{\left[\frac{kg\,m^2}{s^2}\right]}{[s]} = \left[\frac{kg\,m^2}{s^3}\right]$$

Power → [Watt]

$$\boxed{\underline{\underline{\text{Work}}} = \text{Power} \cdot \Delta t}$$

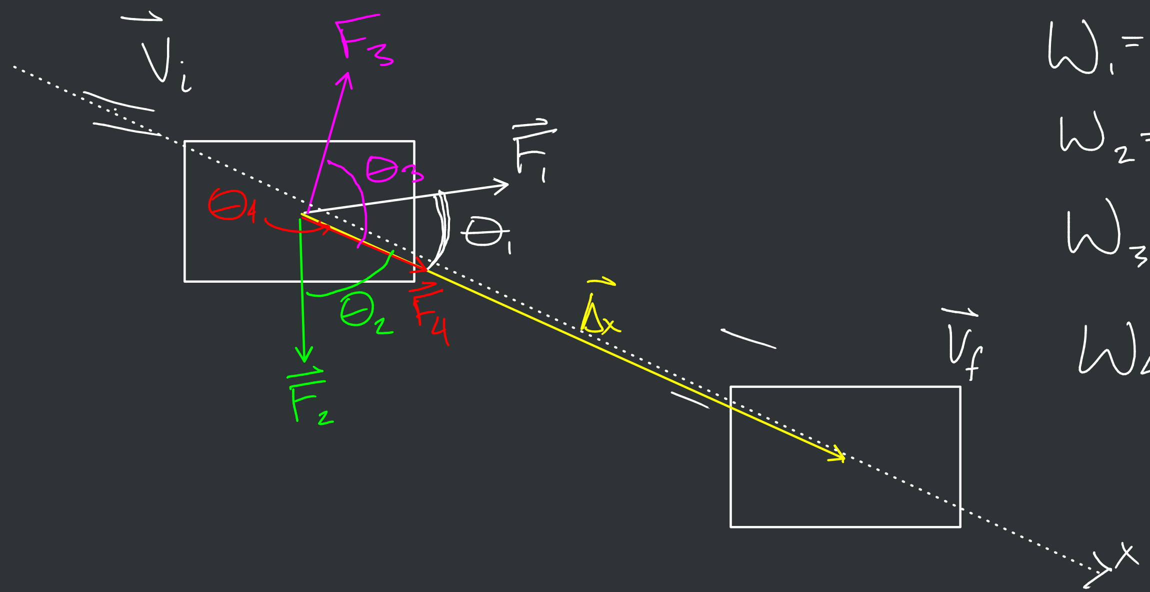
After this you can

- calculate kinetic energy
- calculate total work done
- relate the total work to the change in kinetic energy

$$\text{Work} = F_A \cos\theta \cdot \Delta x$$

$$\text{Work} = F_A \, \Delta x \cos\theta$$

angle between F + Δx



$$W_1 = \underbrace{F_1 \cos\theta_1}_{F_{1x}} \Delta x$$

$$W_2 = F_2 \cos\theta_2 \Delta x$$

$$W_3 = F_3 \cos\theta_3 \Delta x$$

$$W_4 = \underbrace{F_4 \cos\theta_4}_{F_{4,x}} \Delta x$$

$$W_1 + W_2 + W_3 + W_4 = W_{total} = \overbrace{(F_{1x} + F_{2x} + F_{3x} + F_{4x})}^{F_{NET,x}} \Delta x$$

add individual works done = W_{total} = find work of the net force in the displacement direction

$$F_{NET,x} = ma_x$$

$$\frac{F_{NET,x}}{m} = a_x$$

$$v_f^2 = v_i^2 + 2a_x\Delta x$$

$$v_f^2 = v_i^2 + 2\frac{F_{NET,x}}{m}\cdot\Delta x$$

W_{total}

$$v_f^2 = v_i^2 + 2\frac{W_{total}}{m}$$

$$v_f^2 - v_i^2 = \frac{2W_{total}}{m}$$

$$\boxed{\underbrace{\frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2}_{\text{change in something}} = W_{total}}$$

$\Delta \to$ final − initial

Kinetic Energy – energy of motion

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

$$\Delta K = K_f - K_i = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

$$\boxed{\Delta K = W_{total}}$$

work – kinetic energy theorem

→ also applies to not-constant forces

speeding up

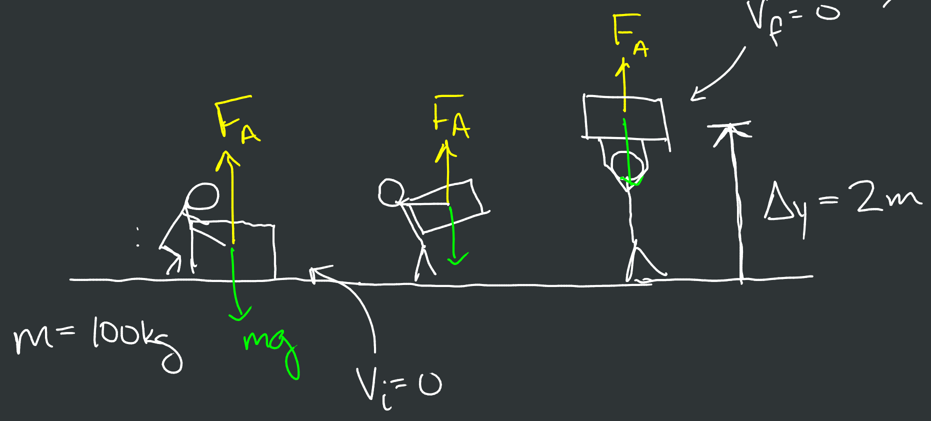
$\Delta K > 0$, $W_t > 0$

$\Delta K < 0$, $W_t < 0$

slowing down

$\Delta K = 0$, $W_t = 0$

← constant velocity



$$\Delta K = K_f - K_i = 0 = W_{total}$$

$$W = |F| \cos\theta \,\Delta y$$

only applies to constant force

$$W_{total} = 0 = \underline{\underline{W_{me}}} + \underline{\underline{W_{grav}}}$$

?

$$W_{grav} = |F_g| \cos\theta \,|\Delta y|$$

mg

$\theta = 180°$

$$W_{grav} = -mg\Delta y \approx \underline{-2000\,J}$$

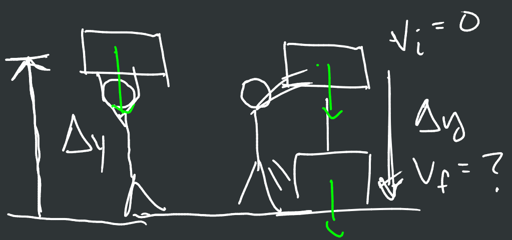
negative work

$$0 = W_{ME} - mg\Delta y$$

positive work

$$\boxed{+mg\Delta y = W_{ME}} = 100\,kg\,(9.8\,N/kg)(2\,m)$$

$$\approx \underline{+2000\,J}$$



$K_f = ?$

$K_i = 0$

$$K_f - \cancel{K_i}^{0} = W_{total} = |F_g| \cos\theta \,|\Delta y|$$

$\theta = 0, \cos 0 = 1$

$$K_f = +mg\Delta y$$

$$\frac{1}{2}\cancel{m} v_f^2 = \cancel{m} g\Delta y$$

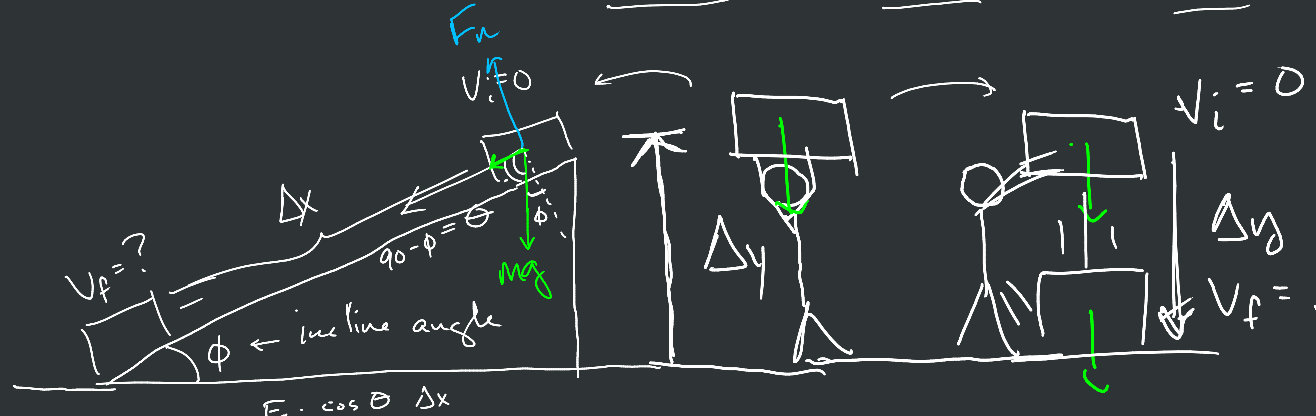
$$v_f^2 = 2g\Delta y$$

$$V_f = \sqrt{2g\Delta y}$$

$$\left(v_f^2 = \cancel{v_i^2}^{0} + 2a\Delta y\right)$$

After this you can

- discuss the meaning of potential energy
- discuss the meaning of conservative forces
- differentiate between a conservative force and a non-conservative force



$F_g \cdot \cos\theta \; \Delta x$

$$W = \underbrace{mg\cos\theta}_{F_{g,x}} \Delta x$$

$\cos\theta = \sin(90 - \theta)$

$\cos\theta = \sin\phi$

$F_{gx} = mg\sin\phi$

$$W = \underbrace{mg\sin\phi}_{F_{NET,x}} \Delta x$$

$$\sin\phi = \frac{\Delta y}{\Delta x}$$

$$W = mg \cdot \frac{\Delta y}{\cancel{\Delta x}} \cdot \cancel{\Delta x}$$

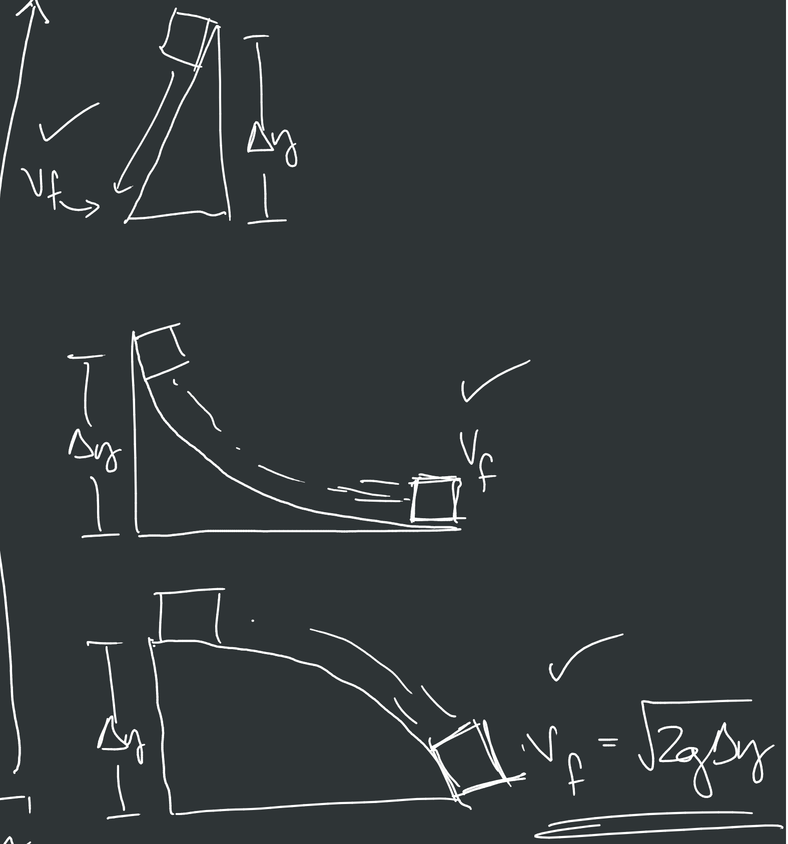
$\boxed{\text{Δx does not matter!}}$

$$W = mg\Delta y$$

$$\Delta K = W = mg\Delta y$$

$K_i = 0 \qquad \Delta K = K_f = mg\Delta y \Rightarrow \frac{1}{2} m v_f^2 = mg\Delta y$

$$v_f = \sqrt{2g\Delta y}$$



lifting the box

$$\Delta K = 0 = W_{total} = W_{ME} + W_g$$

>0 $\quad$ <0 ← what happened?

↳ stored

potential energy is stored energy (depends on position)

force of gravity stores energy in easily accessible way

↳ conservative force

- gravity (gravitational potential energy)
- spring (elastic potential energy)
- electric force (electric potential energy)

non-conservative forces

- friction → energy converted into internal energy
  ↳ object heat up

- applied force → energy from an external source (chemical) goes into internal energy

$$\Delta K = W_{total} = \underbrace{W_{conservative}} + W_{non\ conservative}$$

$$W_{conservative} = -\Delta U$$ ← change in potential energy

mechanical energy

$$\Delta K = -\Delta U + W_{nc}$$

$$\Delta E_{mech} = \Delta K + \Delta U = W_{nc}$$

↓

$$K_f - K_i + U_f - U_i = W_{nc}$$

$$\boxed{K_f + U_f = K_i + U_i + W_{nc}}$$

$\underbrace{K_f + U_f}_{\text{final energy}}$ $\underbrace{K_i + U_i}_{\text{initial energy}}$

W_{nc} → how much energy comes from/goes to surroundings

$W_{nc} > 0$ ← increasing energy of the system

$W_{nc} < 0$ ← decreasing energy of the system → to surroundings

What if $W_{nc} = 0$

- frictionless
- no external force

$$\boxed{\Delta K = -\Delta U}$$

$$\boxed{K_f + U_f = K_i + U_i}$$

After this you can
- calculate the potential energy of an object
- use conservation of energy to solve for an unknown variable

Gravitational Potential Energy

$$-\Delta U_g = W_{cons} = F_g \cos\theta \, \Delta y$$

$$mg \underbrace{\cos 180^\circ}_{-1} \Delta y$$

$\uparrow \Delta y$

$\downarrow F$

$$F_g = mg$$

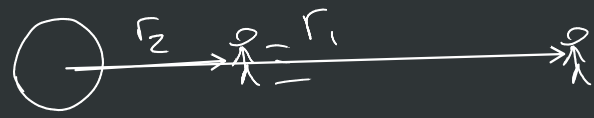
$$-\Delta U_g = -mg\Delta y$$

$$\boxed{\Delta U_g = mg\Delta y}$$

only use change

$U=0,\ y=0$ in potential energy

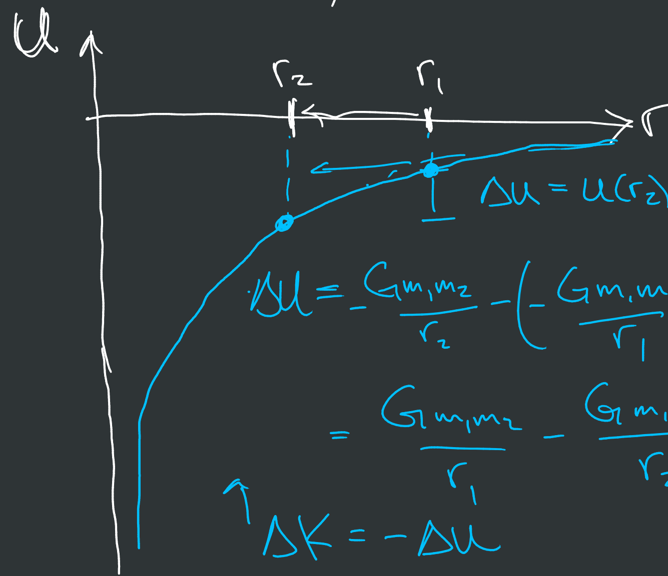
applies near earth's surface



$$F_g = \frac{G m_1 m_2}{r^2}$$

$$U(r) = -\frac{G m_1 m_2}{r}$$

$$U = 0,\quad r \to \infty$$



$$\Delta U = U(r_2) - U(r_1)$$

$$\Delta U = -\frac{G m_1 m_2}{r_2} - \left(-\frac{G m_1 m_2}{r_1}\right)$$

$$= \frac{G m_1 m_2}{r_1} - \frac{G m_1 m_2}{r_2}$$

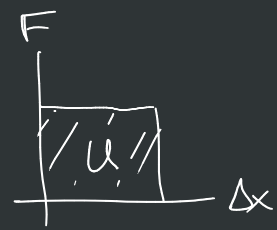
$$\Delta K = -\Delta U$$

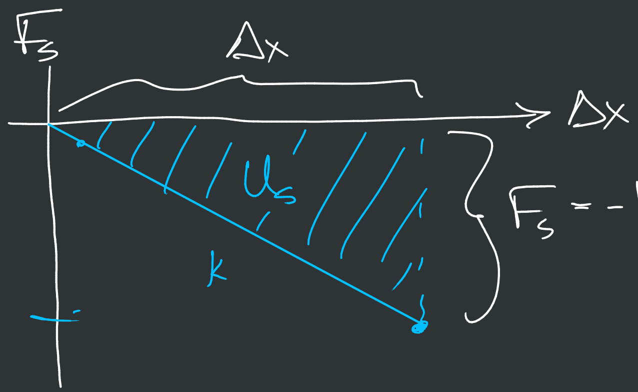
Elastic Potential Energy (Spring Potential Energy)

↳ Hooke's Law ← Spring Force

$$\vec{F}_s = -k\vec{\Delta x}$$ ← non-constant force

$U = F_{const} \cdot \Delta x$





$F_s = -k\Delta x$

$$-\Delta U = W_s$$

$$-\Delta U_s = \frac{1}{2}\Delta x(-k\Delta x)$$

$$-\Delta U_s = -\frac{1}{2}k\Delta x^2$$

$$\boxed{\Delta U_s = \frac{1}{2}k\Delta x^2}$$

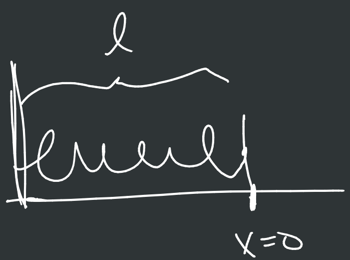
spring constant

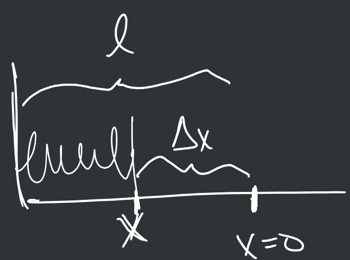
distortion of spring / displacement of the end of the spring

$U = 0$, $x = 0$

unstretched

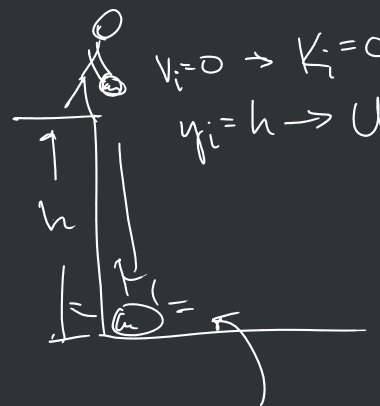
relaxed length





$$K_f + U_f = K_i + U_i + \cancel{W_{nc}} \to 0$$

0, for this example



$v_i = 0 \to K_i = 0$

$y_i = h \to U_{ig} = mgh$

$v_f = ? \to K_f = ?$

$y = 0 \to U_{gf} = 0$

$$K_f + 0J = 0J + U_i$$

$$K_f = U_i$$

conservation of energy

$$K_f = mgh$$

initial potential energy has been converted into kinetic energy later on

$$\frac{1}{2} m v_f^2 = mgh$$

$$v_f = \sqrt{2gh}$$