CHAPTER 6

قانون حفظ الطاقة

Conservation of Energy

- One form of energy can be converted into another form of energy.
- Conservative and non-conservative forces

Kinetic energy: Energy associated with *motion*

Potential energy: Energy associated with *position*

Potential energy U:

- Can be thought of as stored energy that can either do work or be converted to kinetic energy.
- When work gets done on an object, its potential and/or kinetic energy increases.
- There are different types of potential energy:
  - Gravitational energy
  - Elastic potential energy (energy in an stretched spring)
  - Others (magnetic, electric, chemical, ...)

Gravitational Potential Energy

Potential Energy **(PE)** ≡ Energy associated with position or configuration of a mass.

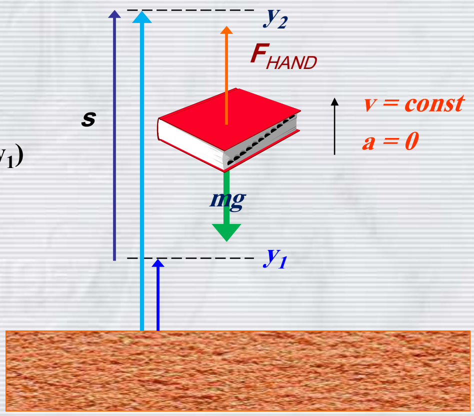
Consider a problem in which the height of a mass above the Earth changes from y_1 to y_2:

W_{grav}=?

UP ➨ $W_g = - mg\ s = - mg\ (y_2 - y_1)$

Down ➨ $W_g = +mg\ s$

$$W_g = - mg\ (y_2 - y_1)$$



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$mgy \equiv U_g \equiv$ gravitational potential energy (PE)

➨ $U_2 - U_1 = \Delta U$

➨ $W_g = - mg\ (y_2 - y_1) = U_1 - U_2 = - \Delta U_g$

$$W_g = - \Delta U_g$$

Changing the configuration of an interacting system requires work

example: lifting a book

The change in potential energy is equal to the negative of the work done

$$\Delta U_g = -W$$

But Work/Kinetic Energy Theorem says: $W = \Delta K$

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

$$\Delta K + \Delta U = 0$$

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Total Mechanical Energy

The change in potential energy is equal to the negative of the work done

$$\Delta U = -W$$

But Work/Kinetic Energy Theorem says: $W = \Delta K$

$$W = -\Delta U = \Delta K \quad \Rightarrow \quad \Delta K + \Delta U = 0$$

$$\Delta K + \Delta U = 0$$
$$K_2 - K_1 + U_2 - U_1 = 0$$
$$K_2 + U_2 = K_1 + U_1 = constant = E \equiv Total\ mechanical\ energy$$

NOTE that the ONLY forces is gravitational energy which doing the work

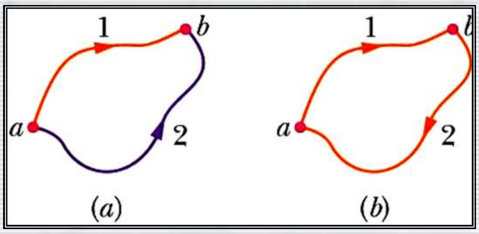
The sum of K and U for any state of the system = the sum of K and U for any other state of the system

In an isolated system acted upon only by conservative forces

Mechanical Energy is conserved

Conservative Forces

(a) A force is conservative if work done by that force acting on a particle moving between points is independent of the path the particle takes between the two points



(b) The total work done by a conservative force is zero when the particle moves around any closed path and returns to its initial position

Work done by gravity

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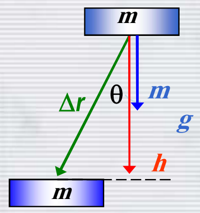
- $W_g = \mathbf{F}.\Delta\mathbf{r} = mg\Delta\mathbf{r}\cos\theta = mg\,h$

  $W_g = mgh$ (Depends only on h!)



$$W_{NET} = W_1 + W_2 + \ldots + W_n$$

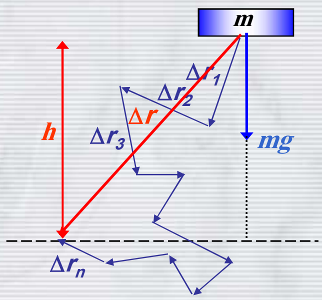
$$= \mathbf{F}\bullet\Delta\mathbf{r}_1 + \mathbf{F}\bullet\Delta\mathbf{r}_2 + \ldots + \mathbf{F}\bullet\Delta\mathbf{r}_n$$

$$= \mathbf{F}\bullet(\Delta\mathbf{r}_1 + \Delta\mathbf{r}_2 + \ldots + \Delta\mathbf{r}_n)$$

$$= \mathbf{F}\bullet\Delta\mathbf{r}$$

$$= F\,\mathrm{h}$$

$$W_g = mg\,h$$



Depends only on h, not on path taken!

Non-conservative forces:

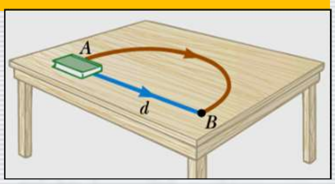
A force is non-conservative if it causes a change in mechanical energy; mechanical energy is the sum of kinetic and potential energy.

Example: Frictional force.

- **This energy cannot be converted back into other forms of energy (irreversible).**
- **Work does depend on path.**

For straight line $W = -f\,d$

For semi-circle path $W = -f(\pi\,d/2)$



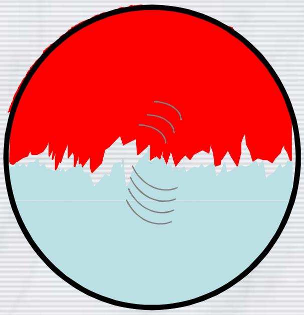
Work varies depending on the path. Energy is dissipated

The presence of a non-conservative force reduces the ability of a system to do work (*dissipative* force)

Energy dissipation: e.g. sliding friction

As the parts scrape by each other they start small-scale vibrations, which transfer energy into atomic motion

The atoms' vibrations go back and forth- they have energy, but no average momentum. The increased atomic vibrations appear to us as a rise in the temperature of the parts. The temperature of an object is related to the thermal energy it has. Friction transfers some energy into thermal energy



When there is NO work done by APPLIED FORCES , the total mechanical energy is constant or CONSEVED

If $W_a \neq 0$ ➡

$K_2+U_2= K_1+U_1+W_a$

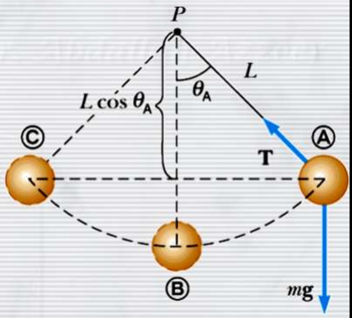
OR $\Delta K + \Delta U = W_{nc}$

W_{nc}= work done by ANY other forces than gravitational force spring forces (e.g. any applied non-conservative force or frictional force)

Example 8.3

Nose crusher?

A bowling ball of mass m is suspended from the ceiling by a cord of length L. The ball is released from rest when the cord makes an angle θ_A with the vertical.



(a) Find the speed of the ball at the lowest point B.

(b) What is the tension T_B in the cord at point B?

(c) The ball swings back. Will it crush the operator's nose?

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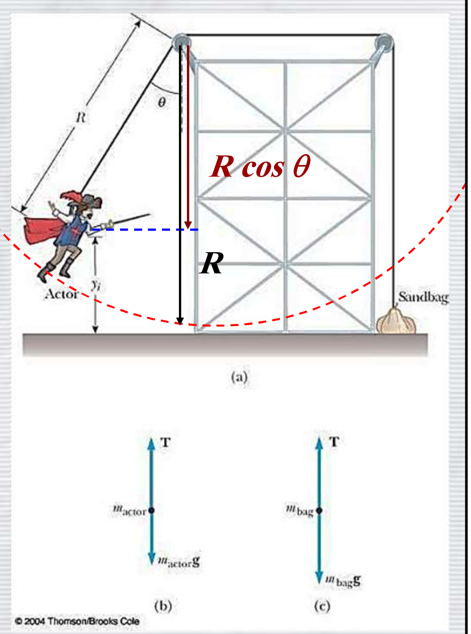
Example

(a) An actor uses some clever staging to make his entrance.

M_{actor} = 65 kg, M_{bag} = 130 kg, R = 3 m

What is the max. value of θ can have before sandbag lifts of the floor?



(b) Free-body diagram for actor at the bottom of the circular path. (c) Free-body diagram for sandbag.

$$K_f + U_f = K_i + U_i$$

$$\frac{1}{2} M_{actor} v_f^2 + 0 = 0 + M_{actor} g y_i$$

$$y_i = R - R\cos\theta = R(1 - \cos\theta)$$

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$$v_f^2 = 2gR(1-\cos\theta)$$

How we can obtain v ????

$$\sum F_y = T - M_{actor}\, g = M_{actor}\frac{v_f^2}{R}$$

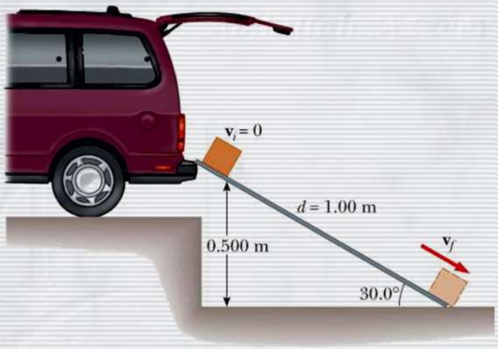
$$\Rightarrow \quad T = M_{actor}\, g + M_{actor}\frac{v_f^2}{R}$$

For the sandbag not to move ➡ $a=0$ ➡ $T=M_{bag}g$

$\theta = 60°$

Example

m = 3 kg , d = 1 m , θ = 30° ,
v_i = 0 , f_k = 5 N , h = 0.5 m ,
v_f = ?



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

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

$$\frac{1}{2}mv_f^2 - 0 + 0 - mgh = -f_k d$$

$$v_f = \sqrt{\frac{2}{m}\left(mgh - f_k d\right)} = 2.54\ m/s$$

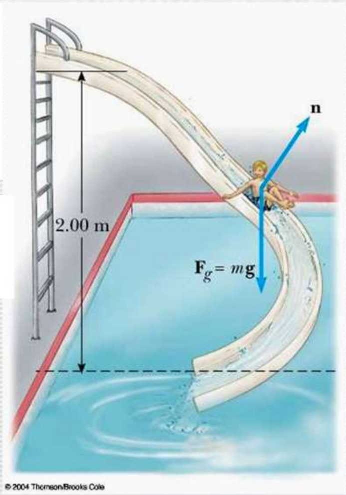
What happen when you don't know h?

Example 8.6

A child of mass m rides on an irregularly curved slide of height $h = 2.00$ m, as shown in Figure 8.12. The child starts from rest at the top.

(A) Determine his speed at the bottom, assuming no friction is present.

(B) If a force of kinetic friction acts on the child, how much mechanical energy does the system lose? Assume that $v_f = 3.00$ m/s and $m = 20.0$ kg.



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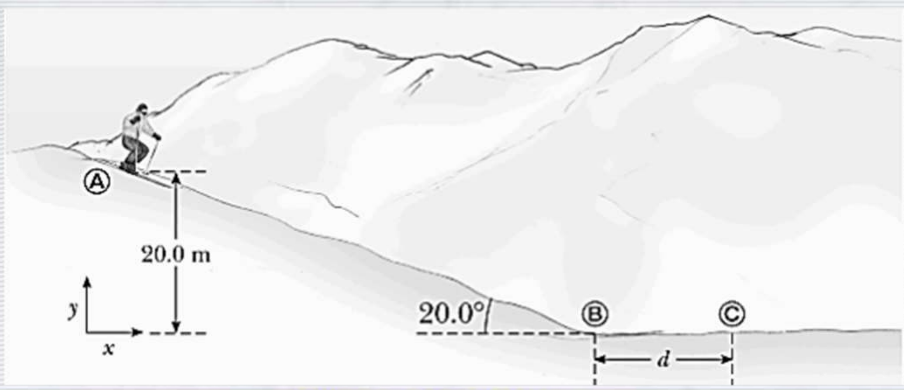
example

A skier starts from rest at the top of a frictionless incline of height 20.0 m, as shown. At the bottom of the incline, he encounters a horizontal surface where the coefficient of kinetic friction between the skis and the snow is 0.210.

(a)How far does he travel on the horizontal stretch.



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$$\Delta E = 0 = \Delta K + \Delta U$$

$$m g h = \frac{1}{2} m v^2$$

$$v = \sqrt{2 g h}$$

$$v = \sqrt{2 \times 9.8 \times 20.0} = 19.8 \ m/s$$

$$\Delta K = K_f - K_i = -f_k d$$

Since $K_f = 0$ $\quad -K_i = -f_k d; \ f_k d = K_i$

$$f_k = \mu_k n = \mu_k m g$$

$$d = \frac{K_i}{\mu_k m g} = \frac{\frac{1}{2} m v^2}{\mu_k m g} = \frac{v^2}{2 \mu_k g} = \frac{(19.8)^2}{2 \times 0.210 \times 9.80} = 95.2 \ m$$

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MINI REVIEW: WORK – KE – PE

Work done by constant force: $W = \mathbf{F} \cdot \mathbf{d} = Fd\cos\theta$

e.g. Work done by gravity: $W_g = -mg\,\Delta y$

Change in gravitational PE: $\Delta U_g = -W_g = mg\,\Delta y$

Work – Energy Thm: $\sum W_{non\text{-}con} = \Delta E_{mech} = \Delta K + \Delta U$

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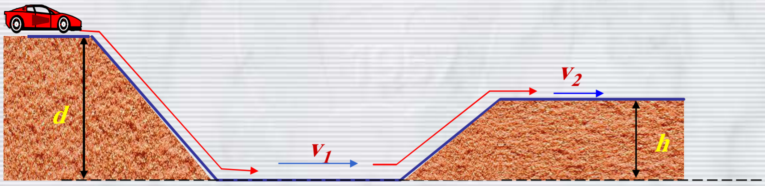
Example : Hotwheel

A toy car slides on the frictionless track shown below. It starts at rest, drops a distance *d*, moves horizontally at speed v_1, rises a distance *h*, and ends up moving horizontally with speed v_2.

Find v_1 and v_2.



- **K+U energy is conserved, so $\Delta E = 0$**

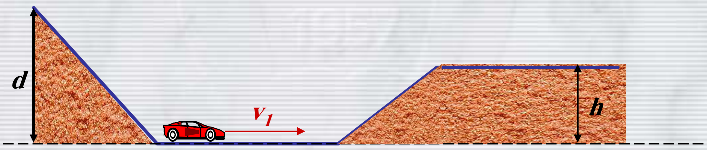
$$\Delta K = -\Delta U$$

- **Moving down a distance *d*,**

$$\Delta U = -mgd, \quad \Delta K = \frac{1}{2} m v_1^2$$

- **Solving for the speed:**

$$v_1 = \sqrt{2gd}$$

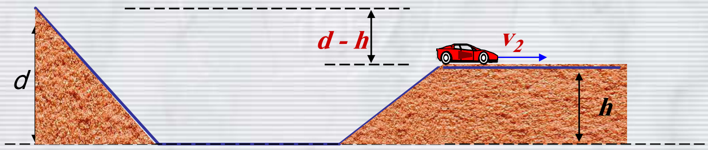


- At the end, we are a distance $d - h$ below our starting point.

$\Delta U = -mg(d - h)$, $\Delta K = \frac{1}{2}mv_2^2$

Solving for the speed:

$$v_2 = \sqrt{2g(d-h)}$$



Example:

With what speed does the weight have just before contact with the nail?

$$\Delta K + \Delta U = 0$$

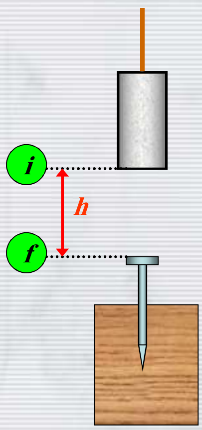
$U_i = mgh$

$U_f = 0$

$K_i = 0$

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

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



What is the force of resistance between the nail and the block?

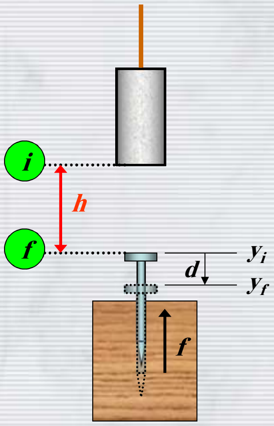
$$\Delta K + \Delta U = W_{nc} = -fd$$

$U_i = 0$

$U_f = -mgd$

$K_i = mgh$

$K_f = 0$



Solve you get

$$f = mg\left(\frac{h+d}{d}\right)$$

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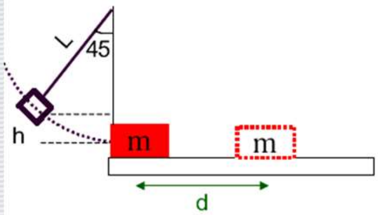
Using Energy to Find Resistive Forces

Pendulum & Sliding Block

What is the work done by friction?



$$KE_i = KE_f = 0$$

$$U_i = mgh = mgL(1-\cos\theta)$$

$$U_f = 0$$

$$\Delta KE + \Delta U = W_{nc}$$

$$W_{nc} = \Delta U = mgL(1-\cos\theta) = -fd$$

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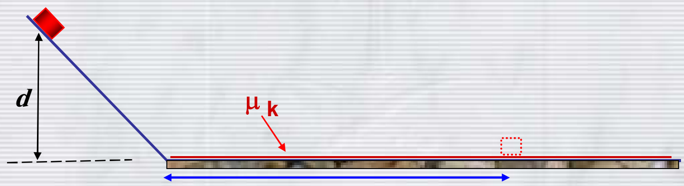
Example;

A block slides down a frictionless ramp. Suppose the horizontal (bottom) portion of the track is rough, such that the coefficient of kinetic friction between the block and the track is μ_k.

How far, x, does the block go along the bottom portion of the track before stopping?



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

As before, $\Delta U = -mgd$

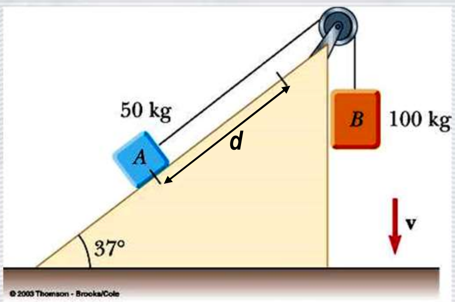
W_{nc} = work done by friction $= -\mu_k mgx$.

$\Delta K = 0$ since the block starts out and ends up at rest.

$W_{nc} = \Delta U$ ⇨ $-\mu_k mgx = -mgd$ ⇨ $x = d/\mu_k$

Example

Two blocks, A and B ($m_A = 50\ kg$ and m_B=100 kg), are connected by a string as shown. If the blocks begin at rest, what will their speeds be after A has slid a distance d = 0.25 m? Assume the pulley and incline are frictionless.



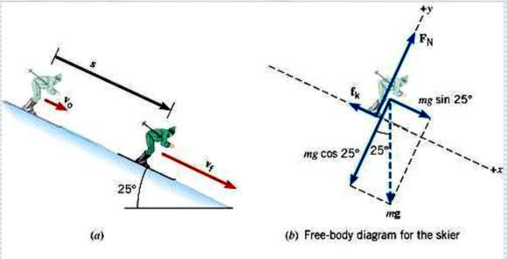
ANS: 1.51 m/s

Example:

A skier (m=58 kg) is traveling down a 25 degree slope. His skies against the snow exert a frictional force of 70 N. He starts out with a velocity of 3.6 m/s. What velocity does he end up with after traveling 57 m downhill?

What is the net force along the direction of the displacement?

$$\sum F_s = mg\sin\theta + (-70N)$$



$$W = \sum F_s \times s = \frac{1}{2}mv^2 - \frac{1}{2}mv_0^2$$

$$[mg\sin\theta + (-70N)] \times s = \frac{1}{2}mv^2 - \frac{1}{2}mv_0^2$$

From this, we can solve for v!

Energy Loss in Automobile

Automobile uses only at 13% of its fuel to propel the vehicle.

Why?

67% in the engine:
1. *Incomplete burning*
2. *Heat*
3. *Sound*

16% in friction in mechanical parts

4% in operating other crucial parts such as oil and fuel pumps, etc

13% used for balancing energy loss related to moving vehicle, like air resistance and road friction to tire, etc

Two frictional forces involved in moving vehicles $m_{car} = 1450kg$ $Weight = mg = 14200N$

Coefficient of Rolling Friction; μ=0.016 $\mu n = \mu mg = 227N$

Air Drag $f_a = \frac{1}{2}D\rho Av^2 = \frac{1}{2}\times 0.5\times 1.293\times 2v^2 = 0.647v^2$ Total Resistance $f_t = f_r + f_a$

Total power to keep speed v=26.8m/s=60mi/h $P = f_t v = (691N)\cdot 26.8 = 18.5kW$

Power to overcome each component of resistance $P_r = f_r v = (227)\cdot 26.8 = 6.08kW$

$P_a = f_a v = (464.7)\cdot 26.8 = 12.5kW$

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SUMMARY

NOT very good for:

1) times
2) directions
3) accelerations

If zero, then mechanical energy is conserved!

$\Delta K = \frac{1}{2} m(v_f^2 - v_i^2)$

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

e.g. work by friction $f_K\, d$

e.g. $\Delta U_g = mg\Delta y$

$\Delta U_{el} = \frac{1}{2} k\, \Delta x^2$

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CONCEPTUAL
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