Energy Conservation II

Force analysis, or energy analysis?

We now have two powerful ways of analyzing physical situations.

1. Analyze forces, apply Newton's Second Law, and apply constant-acceleration equations.
2. Use energy conservation.

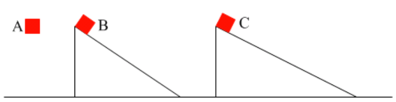
Which method do you use in answering the following?

- How do the speeds of the blocks compare?
- What is the final speed of block C?
- How long does it take block C to reach the floor?

A Race

Three identical blocks are initially the same height above the floor, and are released from rest. Block A falls straight down, while blocks B and C travel down frictionless inclines. Ramp B is steeper than ramp C. Rank the blocks based on the time it takes them to reach the floor.

1. A>B>C
2. A<B<C
3. A=B=C

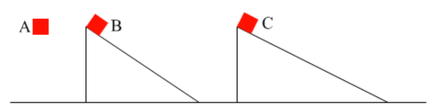


Which method would you use to determine this answer?
1. Newton's 2nd law 2. Conservation of energy

Blocks

Three identical blocks are initially the same height above the floor, and are released from rest. Block A falls straight down, while blocks B and C travel down frictionless ramps. Ramp B is steeper than ramp C. Rank the blocks based on their kinetic energy as they reach the floor.

1. A>B>C
2. A>B=C
3. A=B=C

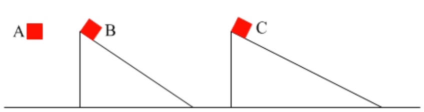


Which method would you use to determine this answer?
1. Newton's 2nd law 2. Conservation of energy

Blocks, with friction

Three identical blocks are initially the same height above the floor, and are released from rest. Block A falls straight down, while blocks B and C travel down ramps. Ramp B is steeper than ramp C, but the coefficient of friction is the same for the ramps. Rank the blocks based on their kinetic energy as they reach the floor.

1. A>B>C
2. A>B=C
3. A=B=C



Which method would you use to determine this answer?
1. Newton's 2nd law 2. Conservation of energy

A block sliding down a ramp 1

A block with a mass of 1.0 kg is released from rest from the top of a ramp that has the shape of a 3-4-5 triangle. The ramp measures 1.8 m high by 2.4 m wide, with the hypotenuse of the ramp measuring 3.0 m. What is the speed of the block when it reaches the bottom, assuming there to be no friction between the block and the ramp?

Solution

If there is no friction,

$W_{nc} = 0$

So $\Delta KE + \Delta PE = W_{nc} = 0$

A block sliding down a ramp 1

	Initial	Final
Speed	$v_0 = 0$	$v_f = ?$
Height	$h_0 = 1.8\text{m}$	$h_f = 0$

ΔKE = -ΔPE

$$\Rightarrow \frac{1}{2}mv_f^2 - 0 = mg(h_f - h_o) = mgh_o$$

$$\Rightarrow v_f = \sqrt{2gh_o} = \sqrt{2\times(10\ \text{m/s}^2)\times 1.8\ \text{m}} = 6.0\ \text{m/s}$$

A block sliding down a ramp 2

For the same problem discussed above, suppose friction is not negligible, and the final speed of the block is 4 m/s (i.e., 2 m/s less than the case without friction). Find the numerical value for the work done by friction on the block and the coefficient of kinetic friction.

A block sliding down a ramp 2

Solution

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

$\Rightarrow \Delta K + \Delta U = W_{nc}$ = Work done by friction

	Initial	Final
Speed	$v_0 = 0$	$v_f = 2$ m/s
Height	$h_0 = 1.8\text{m}$	$h_f = 0$

$$\Rightarrow W_{nc} = \frac{1}{2}mv_f^2 - 0 + mg(0 - h_o)$$

$$= \frac{1}{2}(1kg)(4m/s)^2 + (1kg)(10m/s^2)(-1.8m) = -10J$$

Negative W_{nc} means that the friction (non-conservative force) acts in a direction opposite to the displacement.

A block sliding down a ramp 2

$W_{nc} = -f_k s$

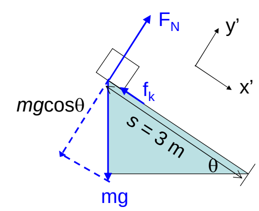
Note the negative sign

$\Rightarrow$ -10 J = $-f_k$ x (3 m)

$\Rightarrow f_k$ = 10/3 N

Since $\Sigma F_{y'} = 0$, we have:

$F_N = mg\cos\theta = 4mg/5 = 0.8mg$



o : a : h = 3 : 4 : 5

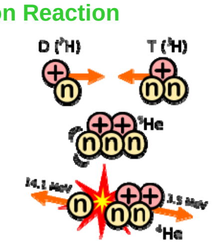
$$\mu_k = \frac{f_k}{F_N} = \frac{10}{3}N\times\frac{1}{(0.8\times 1kg\times 10m/s^2)} = \frac{5}{12}$$

Other Forms of Energies

So far we have discussed only a very small sub-group of energies (including (1) kinetic energy and (2) work done due to nonconservative force and (3) potential energy). There is a vast number of other forms of energies such as heat, chemical energy (stored in our food), electrical energy, sound energy, light energy (that provides the energy required in photosynthesis – a process that green plant leaves synthesis glucose from CO_2 and water), and mass (as in Einstein's relation E = Δmc^2.), *etc*. Together, they warrant that the total energy of the universe in any process is conserved.

Other Forms of Energy: Energy Release in a Fusion Reaction

$^2H + {}^3H \rightarrow n + {}^4He$



The total mass on the L.H.S. is not the same as the total mass on the R.H.S. The energy release in this reaction is Δmc^2. Since $c = 3\times10^8$m/s. The energy release can be very large even though Δm may only be ~1% of a neutron mass. Assuming this mass loss per reaction, the corresponding energy release would be ~240 TJ/kg (Tera means 10^{12})

Principle of Conservation of Energy

Energy can neither be created not destroyed, but can only be converted from one form to another.

This principle applies to mass, which is a form of energy due to the famous relation by Einstein: $E = mc^2$.

A Word about Nonconservative Work Done

Note that the word "non-conservative" carries no implication about whether the non-conservative work done is conserved or not. In general, one should never assume the colloquial meaning of a word that is used for a technical term in physics.

Power

Sometimes, it is desirable to be able to generate energy at a fast enough rate, e.g. when you are climbing a hill. In physics, the rate of generation of energy is called power.

DEFINITION OF AVERAGE POWER

Average power is the rate at which work is done, and it is obtained by dividing the work by the time required to perform the work.

$$\overline{P} = \frac{\text{Work}}{\text{Time}} = \frac{\Delta W}{\Delta t}$$, which is a scalar.

$$\text{joule}/\text{s} = \text{watt (W)}$$

$$\overline{P} = \frac{\text{Change in energy}}{\text{Time}}$$

$$\overline{P} = \frac{\Delta(Fs)}{\Delta t} = F\overline{v}$$ (If F is constant, $\Delta(Fs) = F\Delta s$.)

$$\boxed{\overline{P} = F\overline{v} \quad \text{if } F \text{ is constant}}$$

In general, P = the area under an F-v curve.

Power – Example 1

You move a 10 N object at a constant speed of 2 m/s on a horizontal surface. The coefficient of kinetic friction between the object and the surface is 0.5. How much power is generated by you?

1. 20 W
2. Less than 20 W
3. More than 20 W.

The force you need to generate in order to move the object at a constant speed in the presence of the friction is (10N)(0.5) = 5N. So P = Fv = (5N)(2m/s) = 10 W

Power – Example 2

You move a 10 N object up a **frictionless** incline by at a constant speed of 2 m/s. The incline makes 30° with the horizontal. How much power is generated by you?

1. 20 W
2. 10 W
3. Neither of the above.

The force you need to generate in order to move the 10 N object up the incline at a constant speed is (10N)sin30° = 5N (up the incline). So P = Fv = (5N)(2m/s) = 10 W

Power – Example 3

If the total resistive force (friction + air resistance) acting against the object is 2 N opposite to its direction of motion, how much more power do you need to generate compared to when there's no friction?

1.4 W

2.2 W

3.Neither of the above.

The additional power you need is just the additional force needed (= 2 N) times the speed = (2N)(2 m/s) = 4 W.

Power of a human being

Given that each person consumes about 2000 Calories per day, can you explain the chart below?

Table 6.4 **Human Metabolic Rates**[a]

Activity	Rate (watts)
Running (15 km/h)	1340 W
Skiing	1050 W
Biking	530 W
Walking (5 km/h)	280 W
Sleeping	77 W

[a]For a young 70-kg male.

Power of a human being

Energy consumed per day = 2,000 Cal x 4,186 J/Cal = 8,372,000 J

Average power = 8,372,000 J / (24 x 60 x 60 s) = 96.9 W

This value is comparable to the values shown in the chart for human metabolic rates.

Note that in nutrition, we typically use **C**alories for units of energy, which equals 4,186 J. This is to be distinguished from **c**alories, which equals 1/1000 Calories.