Dynamics and transportation

1) Review of work, energy;
2) PRS questions on work;
2) Introduction to transportation.

Q5. Two balls are dropped from the same height. Ball A has a horizontal initial velocity v, ball B starts from rest. Which one will hit the floor first (assume no drag here):

1. Ball A.
2. Ball B.
3. They will hit the floor simultaneously.
4. Which one will hit first depends on v.

What if drag is nonzero?

Conservation of Energy

No friction or external forces:

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

The total mechanical energy E=K+V of an isolated system does not change or is conserved.

Example: free fall objects (assume drag is negligible);

A skater in energy skate park (frictionless track).

With external forces but no friction

The work done by an external forces on a system is either stored as potential energy and/or it is used to change the kinetic energy.

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

Work

(Mechanical) work:

- $W = F\,d$, where F is the force under consideration and d is the distance traveled.

- +/- signs: If the force is in the direction of motion, work is positive. If they are opposite directions, work is negative.

With friction

Mechanical energy is lost from the system and transformed into heat. This amount that previously called Q is equal to the work done by friction.

$$\Delta U + \Delta K = W_f;$$

$$\mathrm{Re}\, f : \Delta U + \Delta K + Q = 0$$

Friction and air drag are always opposite to the direction of motion. Hence the work done by friction and air drag is always negative.

Work - Energy Principle

- The net work on an object is zero if the net force is zero.
- A non-zero net work means non-zero net force: The object is accelerated resulting in a change in kinetic energy. This is known as work-energy principle.

$$W_{net} = \Delta K = K_f - K_i$$

Example: slowing down of an object due to friction. The work done by the friction force is equal to the loss in kinetic energy (or heat generated). So the net work done on the object is negative here.

Q1

A person is pulling (or pushing) a crate at constant speed with friction. What is the net work done on the crate?

1) Zero.
2) Equal to the pulling force times the displacement.
3) Equal to the friction force times the displacement

Q2

When a person is pulling (or pushing) a crate at constant speed with friction:

1) the work done by the person must be equal to the work done by the friction force.

2) the work done by the person must be greater to overcome friction.

3) the work done by the person is less than the work done by the friction force.

Q3

Assume now that the work done by the person on the crate is larger than the work done by the friction force on the crate. This means that

1) The person pulls the crate inefficiently.
2) The crate is accelerated.
3) The crate is too heavy to overcome static friction.
4) The person is slipping and a part of the work is lost.

Q4

A 4-kg block and a 2-kg block are gliding over a horizontal surface with friction (same μ_k) and are brought to rest. The heavier block has an initial speed of 2 m/s and the lighter block has an initial speed of 4 m/s. Which statement best describes their respective stopping distances?

1) The 4-kg block travels twice as far as the 2-kg mass before stopping.
2) The 2-kg block travels twice as far as the 4-kg mass.
3) Both blocks travel the same distance.
4) The 2-kg mass travels four times as far.

Q5

A 1 kg block sliding on a table with an initial velocity v_i = 3 m/s is coming to rest after 1.5 m. Determine the kinetic friction coefficient.

Hint: $$\Delta U + \Delta K = W_{fr}$$

1) 0.8;
2) 0.6;
3) 0.3;
4) 0.1.

Energy in Transportation

- All transportation systems need energy to
  - accelerate up to speed.
  - Make up for losses due to (rolling) friction, air drag, etc.
  - Air planes need additional energy to climb to an altitude of ~10 km.
- Note that for slowing down (almost) no energy is required in most transportation systems (except air planes or ships).
- We see that energy consumption is linked to mass (acceleration, hills, altitude) and size (drag and resistance forces).

Power

- Power is defined as the rate at which work is done. Average power is the amount of work done in a time interval Δt or the amount of energy transferred:

$$\overline{P} = \frac{W}{\Delta t} = \frac{\Delta E}{\Delta t}$$

SI unit: 1 watt = 1W = 1J/s

- Mechanical power:

$$P_{avg} = \frac{\Delta W}{\Delta t} = \frac{F_{\parallel} \cdot \Delta x}{\Delta t} = F_{\parallel} \cdot v_{avg}.$$

Transportation

Estimate energy consumption from known forces.

--- the gas mileage of a car;

--- Are trains more efficient than cars?

--- Fuel consumed by jet planes flying at an altitude of ~10 km.

- How does the energy efficiency of a bus compare to a car? What's the minimum number of passengers to make the bus more efficient.
- What is the efficiency of a ship?

Example

- In example 5.8 in Knight, the rolling friction and air drag of a car are estimated to be equal at 23 m/s. (m= 1500 kg and μ_r is given as 0.02).

  We check the energy consumption of this car.

- Rolling friction: $f_r = \mu_r\, m\, g$ = 294 N. The air drag is also ~300 N giving a total of 600 N.

- Cars usually have their lowest energy consumption at ~ 80 km/h on an open road and consume 6 – 10 L of gasoline per 100 km depending on size and engine.

Continue….

- In order to maintain speed, the car's engine must do work equal to the work done by friction and air drag:
- W = F d = 600 N x 100 km = 6 x 10^7 J.
- Gasoline has an energy of 34.6 MJ per litre (Wikipedia).
- The consumption is thus ~ 1.7 L.
- But car engines have internal energy losses (cooling, exhaust, friction, etc.) resulting in an efficiency of only ~ 20% (Wikipedia).
- Taking the efficiency into account leads to a realistic answer of 8.5 L/100km.