Momentum in combination; impulse

Physics 211
Syracuse University, Physics 211 Spring 2023
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Announcements

- Upcoming office hours:
  - Today, 3-5 PM
  - Next Wednesday, 3-5 PM
  - Next Thursday, 3-5 PM
- One question on HW5 will involve the material from Thursday
- We usually don't do this, but the alternative is homework over break (which I don't ever do)

There is no recitation Thursday/Friday.

You may turn your homework in to your TA's mailbox.

Conservation of momentum is our best tool for understanding **collisions and explosions**.

How do we deal with situations that involve a collision or an explosion and something else?

- Draw cartoons at critical moments in the motion
    - Right before the collision/explosion
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    - Any others you know about

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  - Make sure you choose notation that is clear
  - Beware of "initial" and "final"

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- Determine *what physical principle* lets you relate each snapshot to the next one
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- Translate those physical principles into equations relating quantities
- Solve the equations for what you need

Easy example: the "knock the box" question from recitation

A harder example: a parking brake failure

A Toyota Yaris (mass 1000 kg) is parked on a hill inclined at 10°. The driver forgot to set the parking brake, and sometime later the car pops into neutral and rolls without friction down the slope.

It rolls into a parked Ford Explorer that has its parking brake set. The coefficient of friction between the Ford and the pavement is $\mu_k = 0.6$. If the cars roll a further 5 meters before they come to rest again, where was the Toyota parked?

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What cartoons of critical moments do I need?

- (1) As soon as the Toyota starts rolling
- (2) Right before the Toyota hits the Ford
- (3) Right after the Toyota hits the Ford
- (4) When the two cars come to rest again

What techniques do I need to relate picture (1) to picture (2) and find a relationship between the starting distance between the cars d and the velocity that the Toyota has right before the collision v_2?

- A: conservation of momentum
- B: kinematics in one dimension
- C: kinematics in two dimensions
- D: force diagrams and $\vec{F} = m\vec{a}$

What techniques do I need to relate picture (2) to picture (3) and find a relationship between the velocity of the Toyota right before the collision v_2 and the velocity of the cars right after the collision v_3?

- A: conservation of momentum
- B: kinematics in one dimension
- C: kinematics in two dimensions
- D: force diagrams and $\vec{F} = m\vec{a}$

What techniques do I need to relate picture (3) to picture (4) and find a relationship between the velocity of the cars right after the collision v_3 and the distance they slide before coming to rest b?

- A: conservation of momentum
- B: kinematics in one dimension
- C: kinematics in two dimensions
- D: force diagrams and $\vec{F} = m\vec{a}$

A harder example: piracy

The dread pirate captain Piarrrrr Squared has a cannon on his ship, mounted on a deck a height h above the waterline. The cannon's mass is a hundred times as large as the cannonballs it fires.

When the cannon fires, it slides back on the deck until friction brings it to rest. If the coefficient of kinetic friction is μ_k, determine how far away from the ship the cannonball will land.

Impulse and momentum

We saw last time that another way to write Newton's law of motion $\vec{F} = m\vec{a}$ is:

$$\vec{F} = \frac{d\vec{p}}{dt}$$

In words:

The force on an object is equal to the rate of change of its momentum.

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The force on an object is equal to the rate of change of its momentum.

We can take integrals of both sides to get an equivalent statement:

$$\int \vec{F}\, dt = \Delta\vec{p}$$

Or, if the force is constant:

$$\vec{F}t = \Delta\vec{p}$$

A force $\vec{F}$ acting on an object for a time t causes a change in its momentum $\vec{F}t$.

Impulse and momentum

The quantity $\int \vec{F}\,dt$ or $\vec{F}t$ is called *impulse*; we use the symbol $\vec{J}$ for it.

So we can say:

The impulse applied to an object is equal to the change in its momentum.

Understanding rockets

Let's apply the impulse-momentum theorem to a rocket.

A rocket is a machine that continuously propels gas backwards at a constant exhaust velocity at a constant rate.

(magnitude of force exhaust exerts on rocket) = (magnitude force rocket exerts on exhaust)

(Newton's 3rd law)

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(impulse-momentum theorem)

rate at which exhaust's momentum changes = rate of mass $\times$ velocity of exhaust

(definition of momentum)

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force rocket exerts on exhaust = rate at which exhaust's momentum changes

(impulse-momentum theorem)

rate at which exhaust's momentum changes = rate of mass × velocity of exhaust

(definition of momentum)

rate of mass × velocity of exhaust = rate of exhausting mass × exhaust velocity

(how a rocket works – continuous flow of gas at constant velocity)

Understanding rockets

Putting all this together, we have:

$$(\text{thrust force on a rocket}) = (\text{mass flow rate}) \times (\text{exhaust velocity})$$