From Last Time...

- Defined mass $m$ and inertia:
  - Mass is amount of inertia of a body
  - Measured in kg
- Defined momentum $p$:
  - $p=mv$, momentum is said to be conserved
- Defined force $F$:
  - Something that changes a body’s velocity
  - Can transfer momentum from one body to another
- Related force, mass, and acceleration:
  - $F=ma$, or $a=F/m$
  - Subject to the same force, more massive objects accelerate more slowly.
- Weight:
  - Force of gravity on a body = $mg$
  - Measured in newtons ($N$). $1 \text{ N} = 1 \text{ kg-m/s}^2$

Newton’s laws

1st law: Law of inertia
Every object continues in its state of rest, or uniform motion in a straight line, unless acted upon by a force.

2nd law: $F=ma$, or $a=F/m$
The acceleration of a body along a direction is
- proportional to the total force along that direction, and
- inversely the mass of the body

3rd law: Action and reaction
For every action there is an equal and opposite reaction.

Q: Force and Diff Masses
A force $F$ acting on an object results in some acceleration $a_1$. The same force on a different object results in twice the acceleration. How does the second mass compare to the first?

A. $m_2=2m_1$
B. $m_2= m_1$
C. $m_2= m_1/2$

Or in words... twice the acceleration means half the mass

Example: More than one force

$M=10 \text{ kg}$, $F_1=200 \text{ N}$

Find $a$

$a = \frac{F_{\text{net}}}{M} = \frac{200\text{ N}}{10\text{ kg}} = 20 \text{ m/s}^2$

$M=10 \text{ kg}$, $F_1=200 \text{ N}$, $F_2=100 \text{ N}$

Find $a$

$a = \frac{F_{\text{net}}}{M} = \frac{(200\text{ N}-100\text{ N})}{10\text{ kg}} = 10 \text{ m/s}^2$

Colliding balls again

Before collision:

During collision

Force on ball 1 decelerates it to zero velocity

Force on ball 2 accelerates it

After collision:

Question

A person weighing 600 N wants to hover using a jet pack. What should the thrust be?

A. 0
B. 600 N
C. 9.8 m/s/s
Question, part 2

- The thrust of the jet pack is increased to 800 N. What is the acceleration of the person?

A. \( g \)  
B. \( \frac{4}{3}g \)  
C. \( g/3 \)

Net force = 800N - 600N = 200N  
What is the mass?  
\( mg = 600N \) (weight), so  
\( m = \frac{600N}{g} \)  
\( a = \frac{F_{\text{net}}}{m} = \frac{200N}{(600N/g)} = g/3 \)

Balancing forces

Force of gravity acts downward on the block.  
But since the block is not accelerating. The net (total) force must be zero.  
Another force is present, which balances the gravitational force.  
It is exerted by the table, on the block.

How can the table exert a force?

- The interaction between the table and the block is a microscopic one.

Force of table on block

- The table can compress, bend, and flex by distorting the atomic positions.  
- The atomic bond is like a spring - it exerts a force on the block.  
- All forces arise at the atomic (or smaller) scale.

3rd law: Law of force pairs

- Every force is an interaction between two objects  
- Each of the bodies exerts a force on the other.  
- The forces are equal and opposite  
  - An action-reaction pair.

Force by the block on you and the earth!

Question, part 1

Suppose you are an astronaut in outer space giving a brief push to a block whose mass is bigger than your own.  
Compare, while you are pushing, the magnitude of the force you exert on the block, \( F_{\text{block}} \), to the magnitude of the force exerted by the block on you, \( F_{\text{Astronaut}} \).  
A. \( F_{\text{Astronaut}} = F_{\text{block}} \)  
B. \( F_{\text{Astronaut}} > F_{\text{block}} \)  
C. \( F_{\text{Astronaut}} < F_{\text{block}} \)

Third law! Equal and opposite reaction force
**Question, part 2**

Compare, while you are pushing, the magnitudes of the acceleration you experience, $\alpha_{\text{Astronaut}}$, to the magnitude of the acceleration of the block, $\alpha_{\text{Block}}$.

A. $\alpha_{\text{Astronaut}} = \alpha_{\text{Block}}$
B. $\alpha_{\text{Astronaut}} > \alpha_{\text{Block}}$
C. $\alpha_{\text{Astronaut}} < \alpha_{\text{Block}}$

\[ a = \frac{F}{m} \]

With the same $F$, the smaller mass has the greater $a$.

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**Identifying forces**

- If horse exerts force on cart, and cart exerts equal and opposite force on horse, how can the cart move?

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**Keep the forces straight!**

- For motion of cart, need to identify the net force on the cart.
- Net horizontal force is force from horse, combined with frictional force of wheels.

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**How can a car move?**

**Vertical forces**
- Gravitational force on car
- Force exerted by road on car

**Horizontal forces**
- Rolling resistance by road on tires
- Drive Force by road on tires

Wheels push push backward against the road, Road pushes forward on the tire.

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**Rockets**

- I apply a force to a ball for a short time $\Delta t$ to get it to move.
- During that time, the ball exerts an equal and opposite force on me!

The forces cause the ball and I to move in opposite directions.

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**Why did the ball and I move?**

The forces resulted in accelerations during the short time $\Delta t$.

\[ \text{Me:} \quad \text{acceleration} = \frac{\text{force}}{\text{mass}} \quad \text{Ball:} \quad \text{acceleration} = \frac{\text{force}}{\text{ball mass}} \]

My acceleration is smaller since my mass is much larger.

The acceleration changes my velocity.

\[ \text{acceleration} = \frac{\text{change in velocity}}{\text{change in time}} \]

\[ \text{force} = \frac{\text{change in time} \times \text{change in velocity}}{\text{mass}} \]
Another explanation

- Before the throw, both the ball and I have zero momentum.
- So the total momentum is zero.

The total momentum is conserved, so after the throw the momenta must cancel:

\[(\text{my momentum}) + (\text{ball momentum}) = 0\]
\[(\text{my mass}) \times (\text{my velocity}) = - (\text{ball mass}) \times (\text{ball velocity})\]

\[(\text{my velocity}) = - (\text{ball velocity}) \times \frac{\text{ball mass}}{\text{my mass}}\]

Equal accelerations

- If more massive bodies accelerate more slowly with the same force...

... why do all bodies fall the same, independent of mass?

- Gravitational force on a body depends on its mass:

\[F_{\text{gravity}} = mg\]

- Therefore acceleration is independent of mass:

\[a = \frac{F_{\text{gravity}}}{m} = \frac{mg}{m} = g\]

A fortunate coincidence

- A force exactly proportional to mass, so that everything cancels nicely.

- But a bit unusual.

- Einstein threw out the gravitational force entirely, attributing the observed acceleration to a distortion of space-time.

Curved space-time

- Bodies obey inertial law

- But the ‘straight-line’ motion appears curved

- Body follows shortest space-time path (geodesic)

- This is a heuristic view of general relativity — an accurate description is quite complicated.

- Will discuss this in Chap. 11