

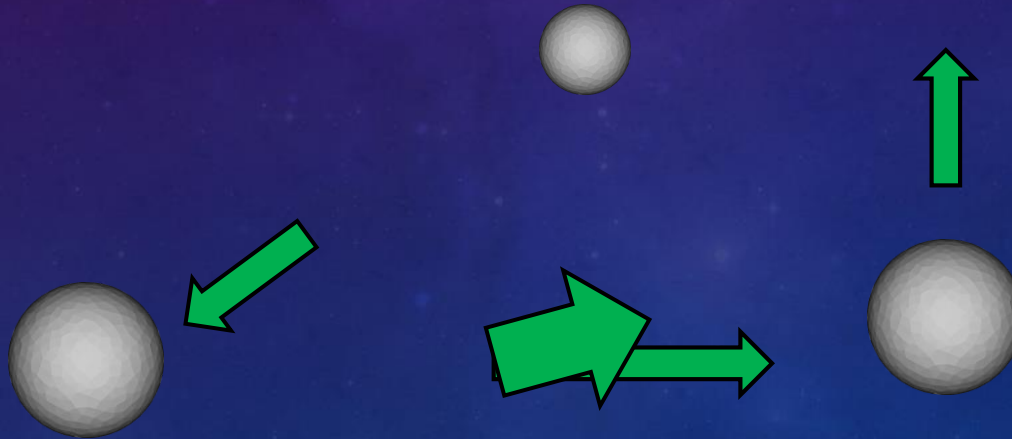
The background features a dark blue gradient with a starry texture. On the left side, there are several overlapping circular elements. A prominent one is a large scale with tick marks and numbers ranging from 140 to 260. Other circles contain curved arrows, some pointing clockwise and some counter-clockwise, suggesting rotational motion or angular momentum. The overall aesthetic is scientific and technical.

# CONSERVATION OF MOMENTUM

PES 1000 – PHYSICS IN EVERYDAY LIFE

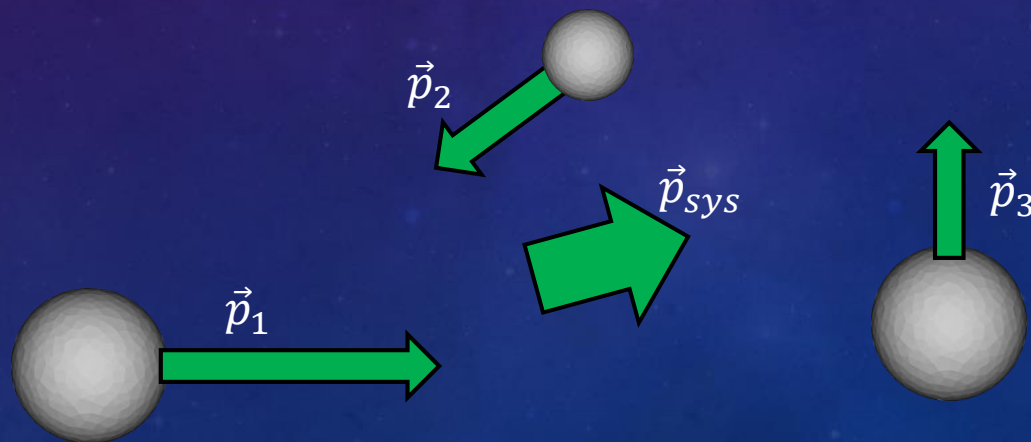
# MOMENTUM OF A SYSTEM OF MOVING OBJECTS

- The **total momentum** of several objects is simply the sum of the individual **momenta**.
- You must add **momentum vectors** by taking both their size and direction into account.
- One way is to add the vectors **tip-to-tail**, like we added **force vectors** together.
- The **total momentum** of the system is the vector from the **tip of the last to the tail of the first**.



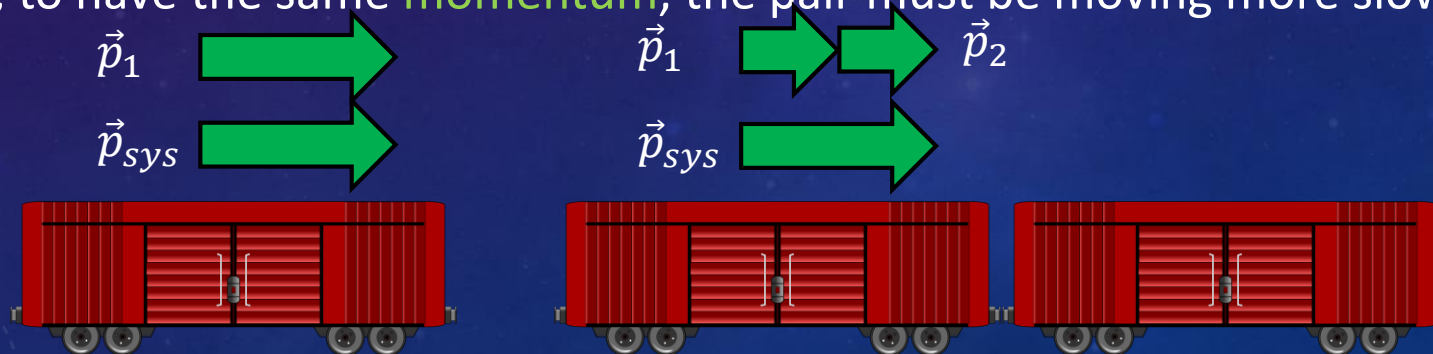
# STATEMENT AND CONDITIONS

- If a system is isolated, it has **no net external force** acting on it, and **no mass is added or removed**.
- Under these conditions, the total momentum of the system will remain unchanged.
- This is called **Conservation of Momentum**.  $\vec{p}_{sys} = \vec{p}_1 + \vec{p}_2 + \vec{p}_3 = constant$
- There may be **internal forces** between the objects, but these are always equal and opposite (Newton's 3<sup>rd</sup> Law), so each pair adds to zero.



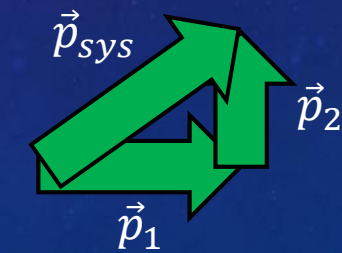
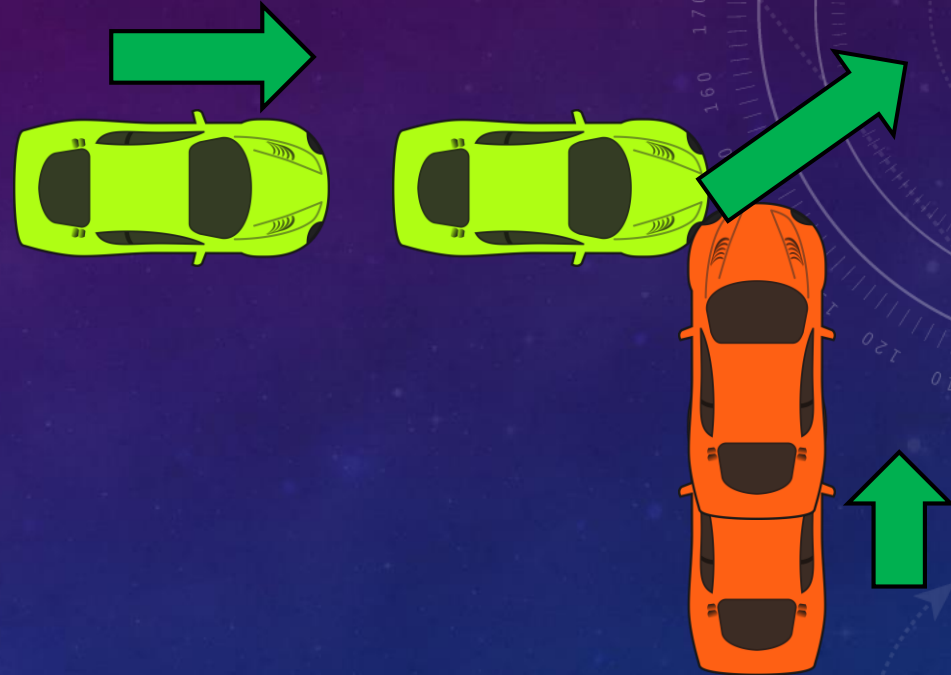
# EXAMPLE: TRAIN CARS

- Two train cars are on a straight, level track. The one in back approaches the one in front, which is stationary, and they lock together.
- This is an isolated system. No net force acts on the system (**gravity** is cancelled by the **normal force**), and no mass is added or removed.
- Car 1 has **momentum**  $\vec{p}_1$ , and car 2 has **no momentum**. The **system momentum** is  $\vec{p}_{sys} = \vec{p}_1$
- During the locking-together, the **forces** are internal and cancel out. So the **total momentum** is unchanged. After the collision, the two cars together have more mass.
- So, to have the same **momentum**, the pair must be moving more slowly.  $\vec{p}_{sys} = \vec{p}_1 + \vec{p}_2$



# EXAMPLE: TWO CARS COLLIDING

- Two cars are trying to stop at an icy intersection, one headed north, one headed east.
- One car has **eastward momentum** and the other has **northward momentum**, so the system before they hit has a net **north-eastward momentum**.
- They collide and lock together.
- The two-car system satisfies the conditions for **conservation of momentum**: no net external force, no mass gain/loss.
- After they lock together, the **momentum** will be the same: **north-eastward**. So the two-car system slides toward the north-east.



Before collision

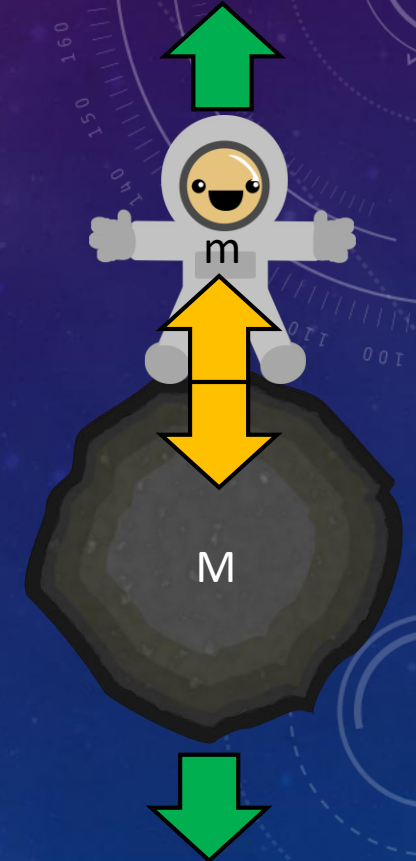


After collision

# RECOIL

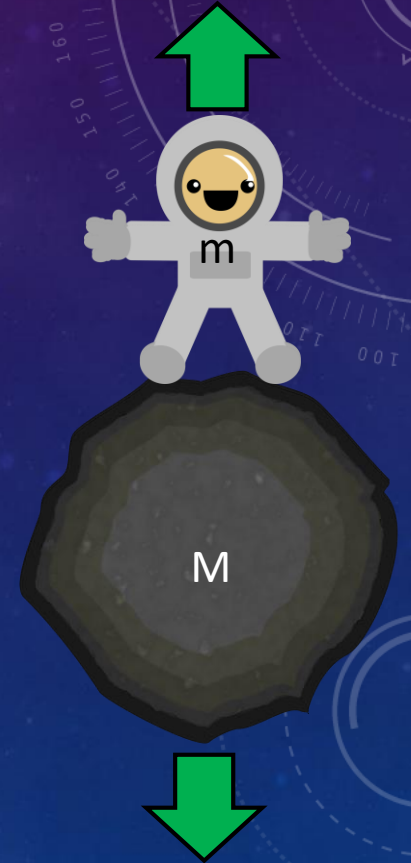
Conservation of momentum plays a role in other interactions, as well.

- An astronaut stands on an asteroid. The system momentum is zero.
- The astronaut pushes downward against the asteroid. The asteroid pushes upward against the astronaut (Newton's 3<sup>rd</sup> Law). These forces are internal to the astronaut/asteroid system.
- Conditions for conservation of momentum are met. So after the interaction, the system momentum is still zero.



# RECOIL

- The astronaut takes **momentum** upward, the asteroid takes the same **momentum** downward, and the vector sum of **momentum** is **zero**.
- The upward **momentum** of the astronaut,  $m \cdot v$ , must equal the asteroid **momentum** downward,  $M \cdot V$ .
- The asteroid's recoil speed,  $V$ , can be found from  $V = \frac{m}{M} * v$
- As you jump away from Earth, the **momentum** you carry up is taken the opposite direction by the Earth, but Earth's recoil speed is immeasurably small because  $M$  is so big.



# GUN RECOIL

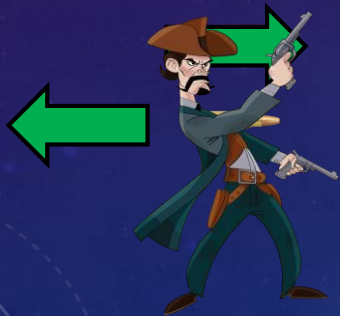
- A gun, when fired, experiences recoil due to **conservation of momentum**. The bullet carries **momentum** away from the gun, and the gun carries this same **momentum** in the opposite direction. 
$$V = \frac{m}{M_{gun}} * v$$

- To keep this from happening, you should hold the gun rigid against your body, so that the recoiling mass is both the gun and you. The recoil velocity will be much less now. 
$$V = \frac{m}{M_{gun} + M_{you}} * v$$

- [Here are some funny gun-recoil videos.](#)

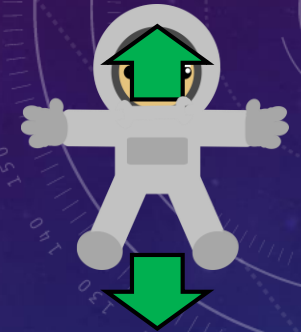
# GUN RECOIL

- Hollywood shoot-out
  - In the movies, the hero shoots a bullet out of his gun, knocking the villain backwards with crushing velocity. **Wrong**
  - In reality, the bullet transfers **momentum** from the hero to the villain. If the **momentum** is great enough to knock the villain backwards, **conservation of momentum** says that the hero must have recoiled with that same **momentum**. Not as dramatically satisfying!



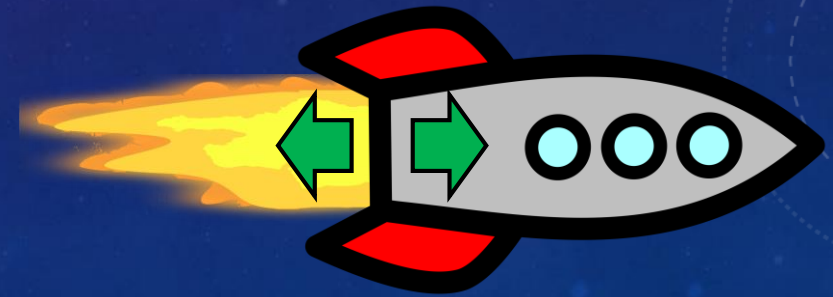
# MOVING IN SPACE

- You are outside the shuttle with your tool belt, working on a satellite, when you realize you left your jetpack onboard. You are stranded. How do you use **conservation of momentum** to get back?
  - Throw your tools in the direction opposite the shuttle. The **momentum** they take in that direction will be countered by your own **momentum** in the direction of the shuttle.



# MOVING IN SPACE

- This is the principle behind rocket propulsion
  - Fuel particles are ejected with **high speed** out the back of the rocket engine by burning them.
  - The particles are small, but have tremendous **speed**, and there are many of them. Together, they carry **momentum** away from the rocket
  - Due to **conservation of momentum**, the rocket takes this same **momentum** in the direction it is pointing.



# CONCLUSION

- The **momentum** of a system of objects is the vector sum of the **momentum** of all the objects.
- If **no net external force** act on the system and **no mass is gained/lost**, then we have **Conservation of Momentum**. The system momentum will be constant.
- When two objects collide, **conservation of momentum** says total momentum before must be the same as total momentum after.
- **Conservation of momentum** lets us calculate the **recoil speed** of two objects that depart each other.
- **Conservation of momentum** also explains how we can move through the vacuum of space.