Review: Newton's 1st & 2nd Laws

- 1st law (*Galileo's principle of inertia*)- no force is needed to keep an object moving with constant velocity
- 2nd law (*law of dynamics*) – a *net force* must be applied to *change the velocity* of an object.
- A force F (N) = m (kg) × a (m/s^2) must be applied to produce an acceleration a for an object of mass m

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L-7 Newton's third law and conservation of momentum

For every action there is an equal and opposite reaction.

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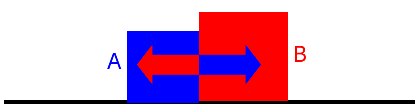
Newton's 3rd Law

If object A exerts a force on object B, then object B exerts an equal force on object A in the opposite direction.



Force that A exerts on B

Force that B exerts on A

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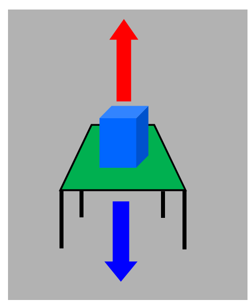
Example: static equilibrium



- What keeps the box on the table?
- The box exerts a force on the table due to its weight, and as result of the 3rd law the table exerts an equal and opposite (upward) force on the box.
- If the table was not strong enough to support the weight of the box, the box would crash through it.

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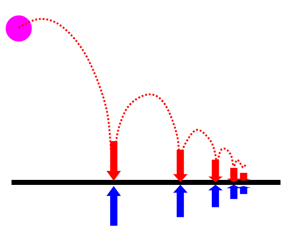
Example: The bouncing ball

- Why does the ball bounce?
- When the ball hits the ground it exerts a downward force on it
- By the 3rd law, the ground must exert an equal and upward force on the ball
- The ball bounces because of the upward force exerted on it by the ground.



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You can move the earth!

- Since the earth exerts a *downward* force on you, the 3rd law says that you exert an *equal upward force* on the earth.
- The *magnitude* of the forces are equal: ➔ $F_{Earth} = F_{you}$, *but are the accelerations equal*?
- **NO**, *because the earth's mass and your mass are not the same!*
- Accelerations are the result of the 2nd law: $F_{Earth} = M_E a_E$ and $F_{you} = m_{you} a_{you}$ → $M_E a_E = m_{you} a_{you}$
- *Therefore*: $a_E = (m_{you} / M_E)\, a_{you}$ ➔ the Earth's acceleration is much less than yours, since (m_{you} / M_E) is a very small number.

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- Newton's 3^{rd} Law plays an important role in everyday life, whether we realize it or not.
- We will demonstrate this in the next few examples.

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The donkey and 3^{rd} law *paradox*

- A man tries to make a donkey pull a cart but the donkey argues:
- Why should I even try?
- No matter how hard I pull on the cart, the cart pulls back on me with an equal force, so I can never move it. *What is the fallacy in the donkey's argument?*
- The donkey forgot that action/reaction forces always act on different objects. As far as the cart is concerned, if the force the donkey exerts on it is large enough, it will move. The reaction force on him is irrelevant.

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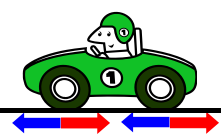
Friction is essential to movement



- The tires push back on the road and the road pushes the tires forward.
- If the road is slippery, the friction force between the tires and road is reduced, and the car does not move.

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We could not walk without friction

- When we walk, we push back on the ground
- By the 3^{rd} law the ground then pushes us forward.
- If the ground is slippery, we cannot push back on it, so it cannot push forward on us → we go nowhere!

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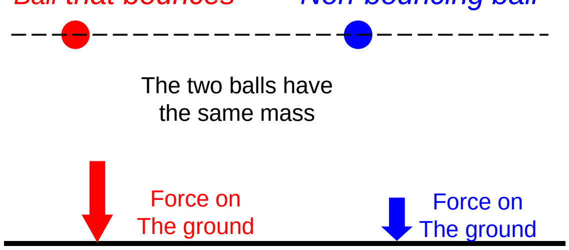
Do 2 balls released from the same height exert the same force on the ground? *It depends . . .*

Ball that bounces *Non-bouncing ball*

The two balls have the same mass



The ball that bounces exerts a larger force on the ground.

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Bouncing and Non-bouncing balls

- The ball that bounced exerted the larger force on the ground.
- The force that the ball exerts on the ground is equal to and in the opposite direction as the force of the ground on the ball.
- The ground must exert a force to bring the non-bouncy ball to rest
- The ground must not only stop the bouncy ball, but must then project it back up → this requires more force!
- Since the bouncy ball experiences a larger force from the ground, it must therefore by the 3^{rd} Law also exert a larger force ON the ground.
- The next demo should convince you!

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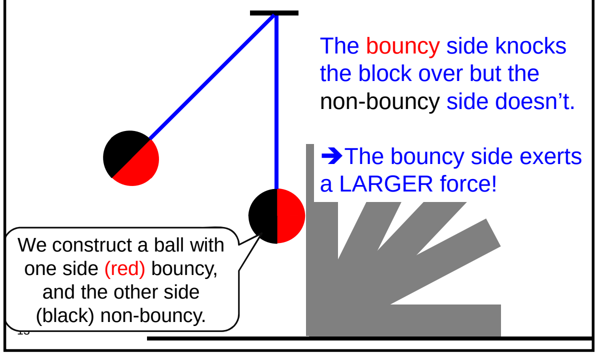
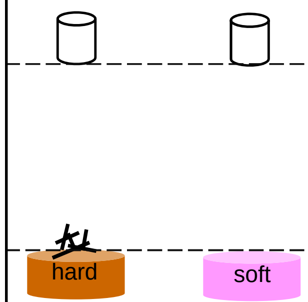
Knock the block over



The bouncy side knocks the block over but the non-bouncy side doesn't.

➔The bouncy side exerts a LARGER force!

How do stunt actors survive falls?



- Instead of actors we will use glass beakers
- The beakers are dropped from same height so then have the same velocity when they reach the bottom.
- One falls on a **hard surface** – a brick
- The other falls on a **soft cushion**

But why does the beaker break?

- An object will break if *a large enough force* is exerted on it. Obviously, the beaker that hits the brick experiences the larger force, *but can we explain this using Newton's Laws?*
- Notice that in both cases, the beakers have the *same velocity* just before hitting the cushion or the brick. Also both beakers come to rest (one gently, the other violently) so their final velocities are both zero.
- Both beakers therefore experience the same *change in velocity* = Δv (delta Δ means change), so that the change in v

$$\Delta v = v_f - v_i = 0 - v_i = - v_i$$

- What about their acceleration?
- a = Δv / Δt, where Δt is the time interval over which the velocity changes (the time to stop)

Continued from previous slide

- The stopping time Δt is the important parameter here because it is *not the same* in both cases.
- The beaker falling on the cushion takes longer to stop than the one falling on the brick. The cushion allows the beaker to stop gently, while the brick stops it abruptly
- Both beakers have the same velocity just before hitting the bottom, and both come to rest, so the change in velocity is the same in both cases.
- However, the beaker that hits the brick, is stopped suddenly and thus experiences a greater acceleration and a greater force which cause it to shatter.

Stunt actors and air bags

- The same reasoning applies to stunt actors and air bags in an automobile.
- Air bags deploy very quickly, triggered when an unusually large acceleration is detected
- They provide protection by allowing you to stop more slowly, as compared to the case where you hit the steering wheel or the windshield.
- Since you come to rest more slowly, the **force** on you is smaller than if you hit a hard surface.
- Some say: "Airbags slow down the force." Although this is not technically accurate, it is a good way of thinking about it.

Momentum

- Newton's 3rd law leads directly to the concept of (linear) momentum
- Momentum is a term used in everyday conversation, e.g., "*The team has momentum,"* or, *"The team lost its momentum."*
- These phrases imply that if you get momentum, you tend to keep it, but when you loose it, it is hard to get it back.
- This colloquial usage is similar to a concept we will discuss – *the law of conservation of momentum* – a law that is very useful in understanding what happens when objects collide.

Physics definition of momentum (p)

- In physics, every quantity must be unambiguously defined, with a prescribed method for measurement
- Momentum:
  - object of mass m, velocity v: $p = m\,v$
  - units of p: kg m/s
- An object with small m and large v, can have a comparable momentum as a very massive moving more slowly.
- e. g., (a) m = 2 kg, v = 10 m/s → p = 20 kg m/s
  (b) m = 5 kg, v = 4 m/s → p = 20 kg m/s

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Conservation of momentum in collisions

- The collision of 2 objects can be very complicated; large forces are involved (which usually cannot be measured) which act over very short time intervals
- Even though the collision forces are not known, the 3rd law ensures that the forces that the objects exert on each other are equal and opposite – this is a very big simplification
- Application of Newton's 3rd and 2nd laws leads to the conclusion that in the collision, the total momentum of the two objects before the collision is the same as their total momentum after the collision – this is called conservation of momentum.

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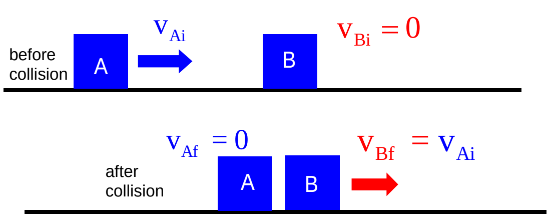
Example of momentum conservation in a collision of two identical objects, one (B) initially at rest



- The sum of the momentum of A and B before the collision = the sum of the momentum of A and B after the collision.
- In the next lecture, we will discuss other types of collisions

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