PURDUE UNIVERSITY DEPARTMENT OF PHYSICS

Physics 22000

General Physics

Lecture 3 – Newtonian Mechanics

Fall 2016 Semester

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Review of Lectures 1 and 2

- In the previous lectures we learned how to describe some special types of motion:
  - Linear motion (ie, in a straight line)
  - Constant acceleration (which includes $a = 0$)
- We described this motion using:
  - Motion diagrams
  - Position vs time graphs
  - Velocity vs time graphs
  - Algebra: $\boldsymbol{x(t) = x_0 + v_{0x}t + \frac{1}{2}a_x t^2}$

$$\boldsymbol{v_x(t) = v_{0x} + a_x t}$$

Acceleration

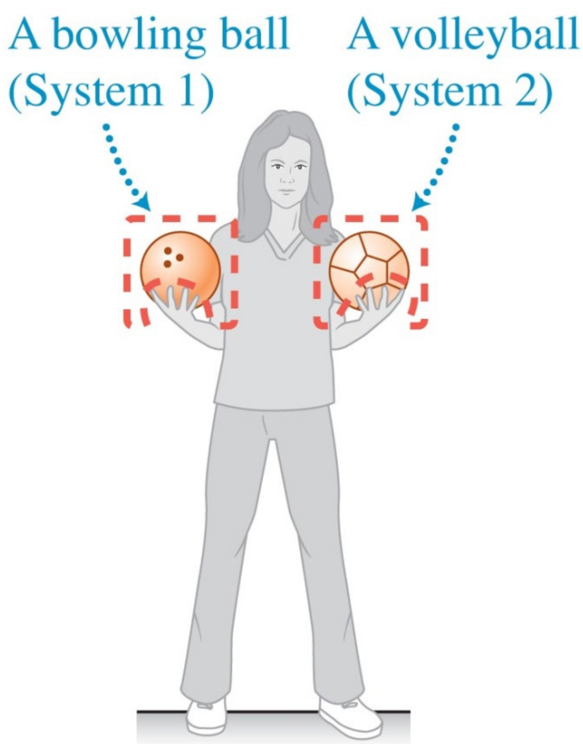
- We described motion of objects that had constant acceleration
- We have not yet asked what causes objects to accelerate
- For an object to accelerate, it must interact with another object
  - They can interact directly when they touch each other (eg, objects push or pull each other)
  - They can interact at a distance (eg, magnets)

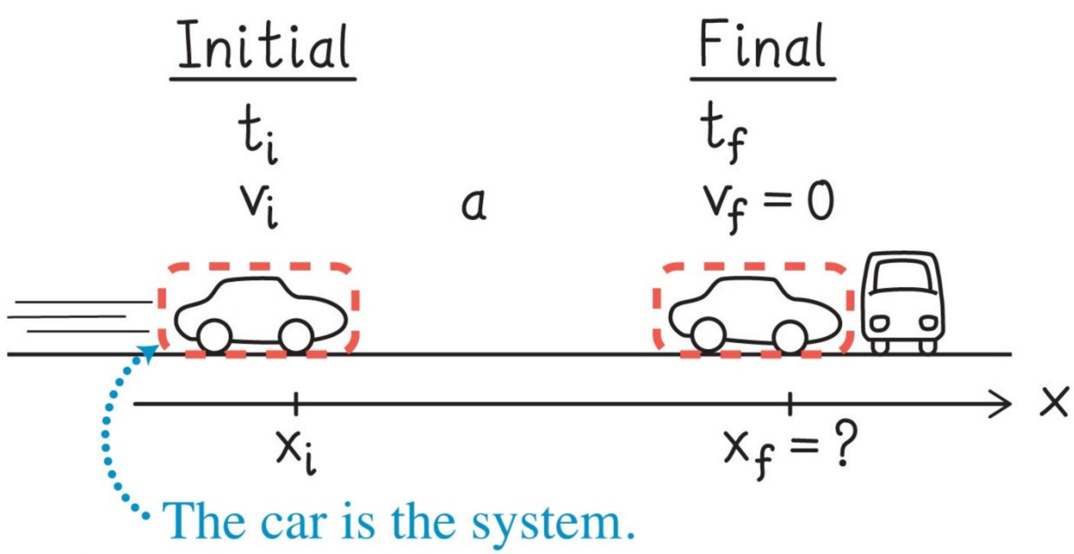
Describing Interactions

- We have two objects, but we are usually interested in describing the motion of one of them at a time.
  - This object is called the ***system***
  - All objects that are not part of the system but can interact with it are in the system's ***environment***
- Interactions between the system object and objects in its environment are called external interactions
  - External interactions can affect the motion of the system object.

Choosing System Objects

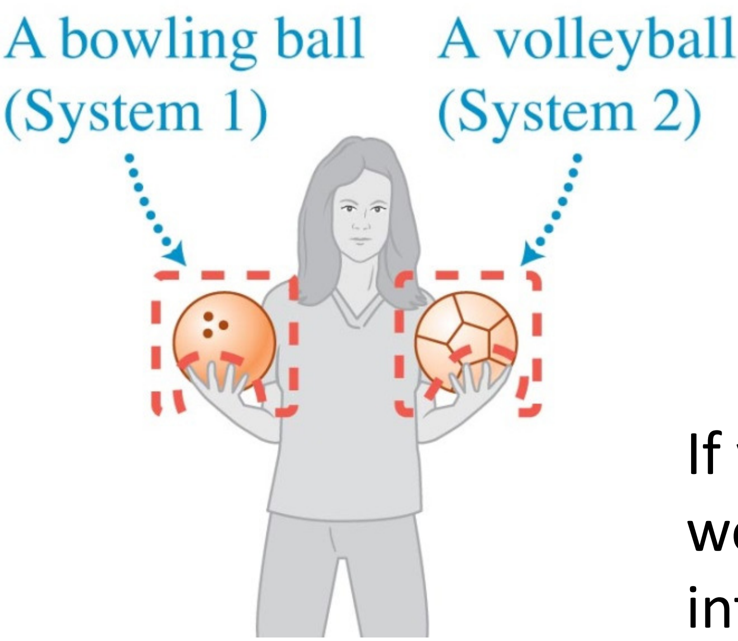
- Which object are we considering?
- Which object is moving and is this the motion we are trying to describe?

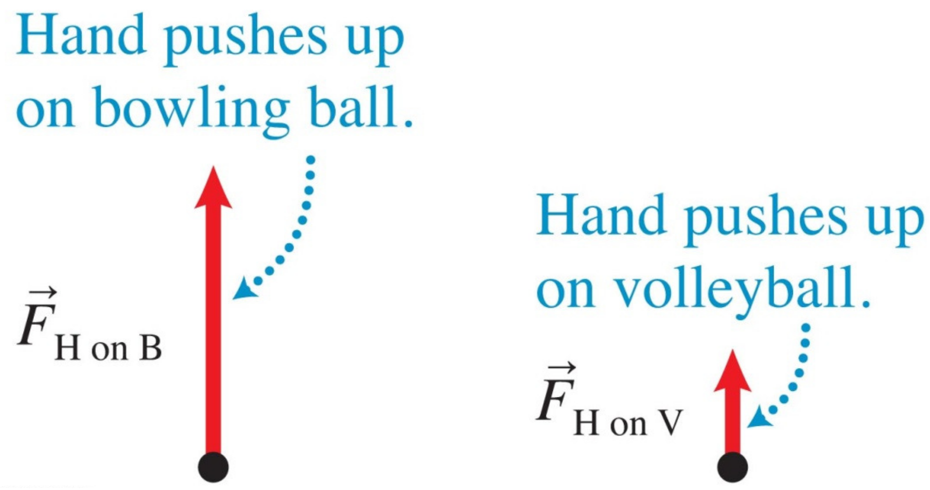




Representing Interactions

- We represent interactions between the system and the environment by arrows.

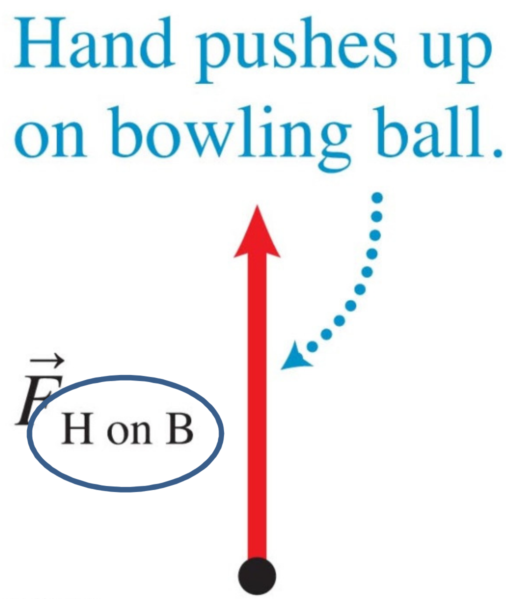


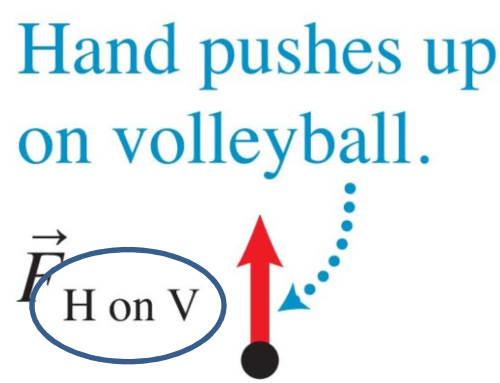


If you were holding both balls, you would realize that whatever the interaction is, it is “stronger” for the bowling ball than for the vollyball.

Force

- Force is a vector quantity that characterizes how hard (magnitude) and in what direction an external object pushes or pulls on a system object.
- We use subscripts to identify the external object that exerts the force and the system object on which the force is exerted.





The SI unit for force is the newton (N).

Force Diagrams

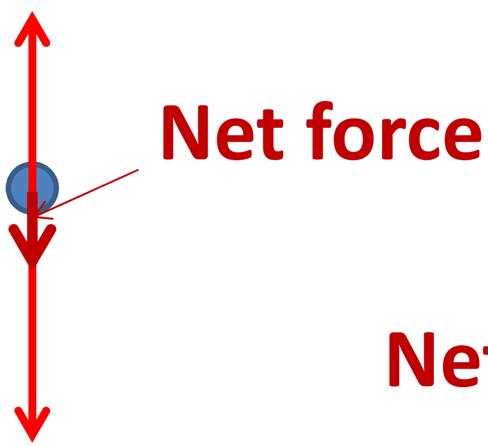
- Used with the point-like model for objects
  - The system object is represented by a dot
- Arrows represent the forces
  - Length of an arrow indicates the strength of the force
  - Direction the arrow points relates to the direction in which the force is exerted on the object
- Includes forces exerted on the system object
- Shows the forces at a single instant in time

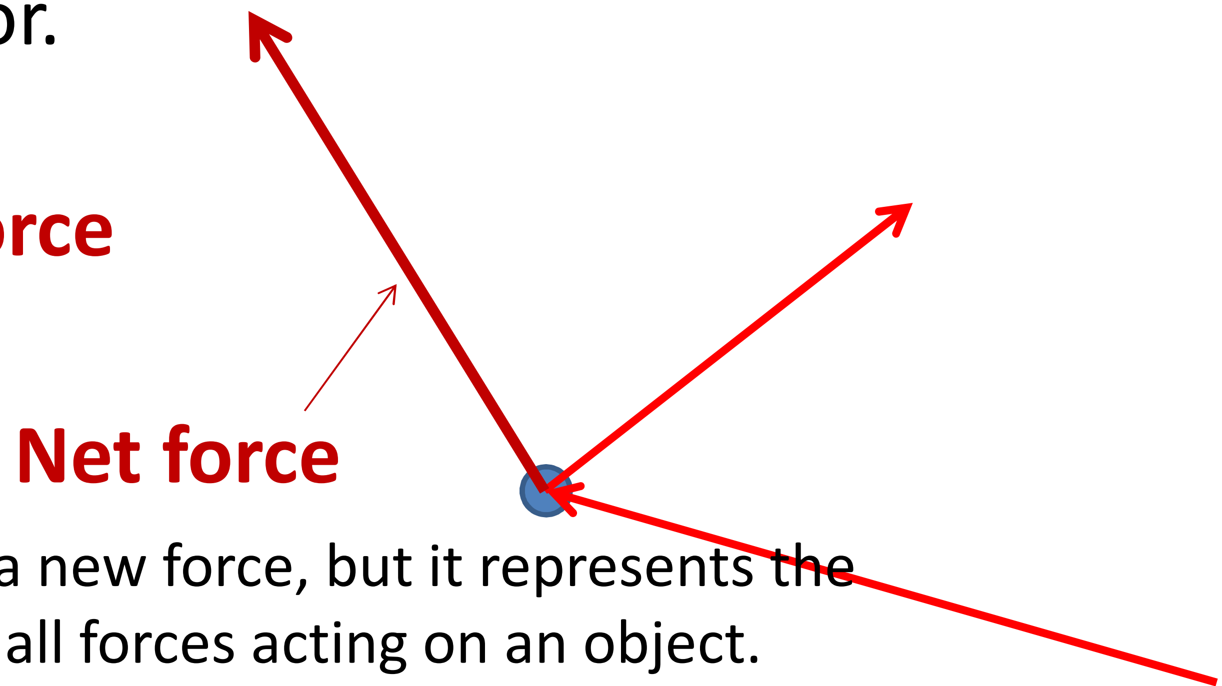
Normal Forces

- Forces perpendicular to a surface are called ***normal*** forces
- We usually label normal forces with the letter $\boldsymbol{N}$
- Normal forces are contact forces due to objects touching each other
- Normal forces are always perpendicular to a surface, but not necessarily vertical
- Examples?

Adding Forces Graphically

- Draw the force vectors head to tail
- The ***net force*** is the vector that goes from the tail of the first vector to the head of the second vector.





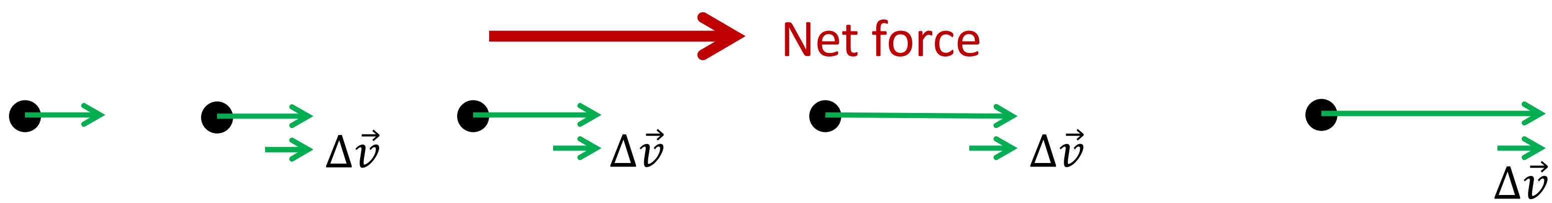
The net force is not a new force, but it represents the combined effects of all forces acting on an object.

Measuring Force Magnitudes

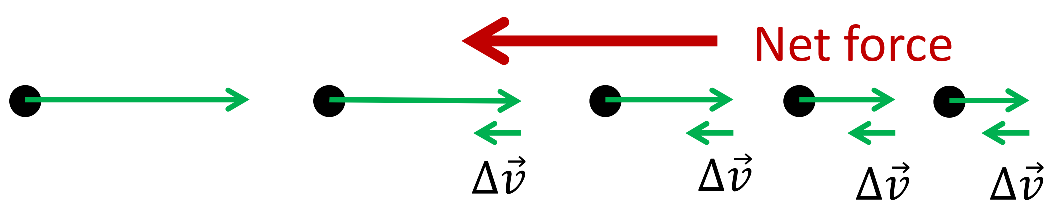
- A spring is a simple device that can be used for measuring forces
- The amount it is compressed or stretches can be calibrated using a known standard force
- An unknown force that compresses or stretches the spring by the same amount must be equal to the force used for calibration
- Springs are often linear – twice the force stretches the spring twice as much.

Relating Force and Motion

- A ***net force*** on an object changes its motion
- If the net force is in the direction of its velocity, then the object speeds up



- If the net force is in the direction opposite the velocity, then the object slows down



Inertial Reference Frames

- An inertial reference frame is one in which an observer
  - Sees that the velocity of the system object does not change if no other objects exert forces on it

OR

  - Sees no change in the velocity if the net force exerted by all objects on the system object is zero
- In a non-inertial reference frame, the velocity of the system object can change even though the sum of forces exerted on it is zero.

(A Non-Inertial Reference Frame)

- Unless you are driving at a constant velocity in a straight line, this is not an inertial reference frame.
- The velocity of the coffee cup (in the reference frame of the car) might suddenly change if the car accelerates.

Newton's First Law of Motion

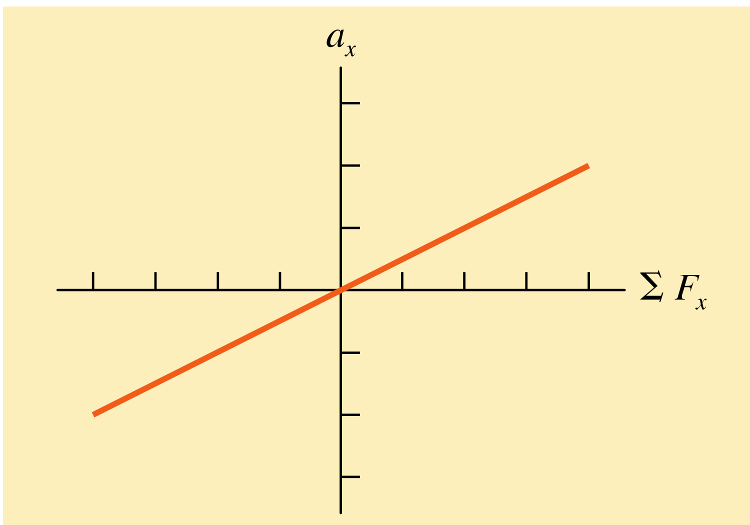
- For an observer in an inertial reference frame, an object will continue to move at constant velocity (or remain at rest)
  - When no other objects exert forces on the system object

  OR

  - When the net force exerted on the system object is zero
- Inertia refers to the characteristic that objects have for continuing to move at constant velocity when the net force exerted by other objects is zero.

Force and Acceleration

- In an inertial reference frame, if the net force is not zero, what is the resulting acceleration?



$$\vec{a}_x \propto \sum \vec{F}_x$$

- We observe a linear relation between force and acceleration.

Newton’s Second Law of Motion

- The resulting acceleration of a system object is proportional to the net force acting on the system object

$$\vec{a}_x \propto \sum \vec{F}_x$$

- The resulting acceleration is in the same direction as the net force acting on the system object.
- They are proportional: if the net force doubles, the resulting acceleration will also double.

Mass

- ***Mass*** is a measure of the amount of matter
- We represent mass by the symbol, $\boldsymbol{m}$**.**
- The SI standard unit for measuring mass is the kilogram (kg)
- The “standard kilogram” is located somewhere near Paris.
- Roughly defined as the mass of water contained in a cube measuring 10 cm on each side.

Newton's Second Law of Motion

- We observe that the acceleration of system objects, when subjected to the same force, is inversely proportional to their mass.

$$a \propto \frac{1}{m}$$

- Combining these results, we find that

$$\vec{a}_{system} = \frac{\sum \vec{F}_{on\ the\ system}}{m_{system}}$$

- Units of force are the Newton: $1\ \mathrm{N} = 1\ \mathrm{kg} \cdot \mathrm{m/s^2}$
- Remember that when we add vectors, we must take into account their directions!

Components of Force Along one Axis

- Newton's second law can be written for the components of acceleration and force in a particular direction.
  - For example, along the x-axis:

$$a_x = \frac{\sum F_x}{m}$$

    - a_x is the acceleration of the system object in the x-direction
    - $\sum F_x$ is the net force in the x-direction acting on the system object
    - m is the mass of the system object
  - Forces that point in the positive direction have a positive component along that axis. Forces pointing in the negative direction have a negative component.

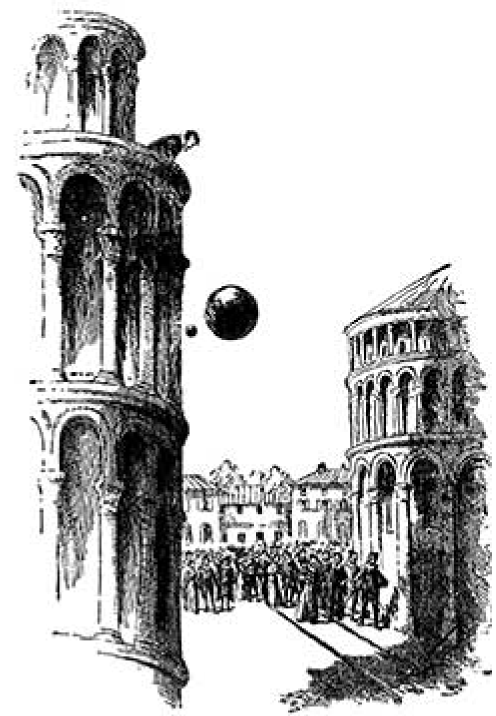
Gravitational Force Law

- In the absence of air resistance (or in a vacuum), all objects fall straight down with the same acceleration.
  - This acceleration has a magnitude of approximately $9.8\, m/s^2$ near the earth's surface.
- The earth (E) exerts the only force on a falling object (O) (in a vacuum)

$$F_{E\ on\ O} = m_O\, a_O = m_O\, (9.8\, m/s^2)$$

- We define $\boldsymbol{g}$ such that

$$F_{E\ on\ O} = m_O\, \boldsymbol{g}$$
$$\boldsymbol{g} = \mathbf{9.8}\, \boldsymbol{N/kg}$$



Weight

- The weight of the object on a planet is the force that the planet exerts on the object.
- In everyday language, the normal force that a scale exerts on you (which balances the downward force you exert on it) is your weight.
- We will not use the term "weight of an object" because it implies that weight is a property of the object rather than an interaction between two objects.

Forces Always Come in Pairs

- Suppose you and a friend are skating at Tapawingo park…
- If you push your friend, they will move away from you (they accelerate).
- But you also move away from them (you also accelerate).

- Because the accelerations were in opposite directions, the forces must point in opposite directions.

Newton's Third Law of Motion

- When two objects interact, object 1 exerts a force on object 2. But object 2 exerts a force on object 1.
  - These forces are equal in magnitude but opposite in direction

$$\vec{\boldsymbol{F}}_{\boldsymbol{object}\,\mathbf{1}\,\boldsymbol{on}\,\boldsymbol{object}\,\mathbf{2}} = -\vec{\boldsymbol{F}}_{\boldsymbol{object}\,\mathbf{2}\,\boldsymbol{on}\,\boldsymbol{object}\,\mathbf{1}}$$

- *These forces are exerted on different objects and cannot be added to find the sum of the forces acting on one object.*

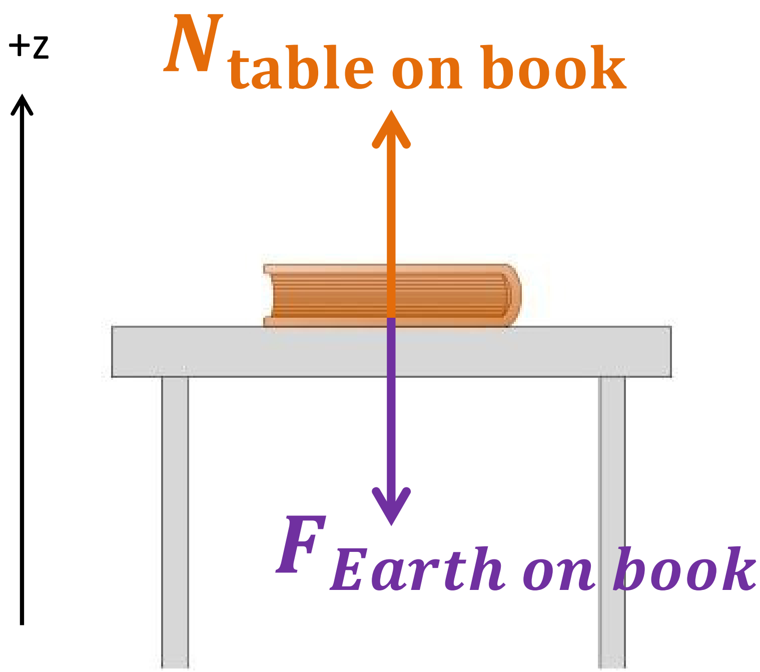
Tips for Newton's Third Law of Motion

- The forces in Newton's third law are exerted on two different objects
  - *This means that the two forces will never appear on the same force diagram*
  - *They should not be added together to find the net force on one of the objects*
  - *You have to choose the system object and consider only the forces exerted on it!*

Example

- The book is the system object
- The book interacts with

(a) The table (a normal force)
(b) The earth (gravity)



The table exerts sufficient normal force to keep the book from sinking into the surface.

The book must remain in contact with the table to be influenced by this force.

- If the mass of the book was 2 kg, then the Earth exerts a force of $F_{E\ on\ B,z} = m\ g_z = (2\ kg)(-9.8\ N/kg) = -19.6\ N$
- Therefore, $F_{T\ on\ B,z} = +19.6\ N$.

Example

- If the book slides with constant velocity along the surface of the table, the only interactions are still just due to the table and the Earth (normal force and gravity)
- But when it slides off the edge of the table, the only force is gravity.
- The book accelerates (in the downward direction):

$$a_z = \frac{F_z}{m} = \frac{-18.6\ N}{2\ kg} = \frac{-18.6\ kg \cdot m/s^2}{2\ kg} = -9.8\ m/s$$

(as expected)