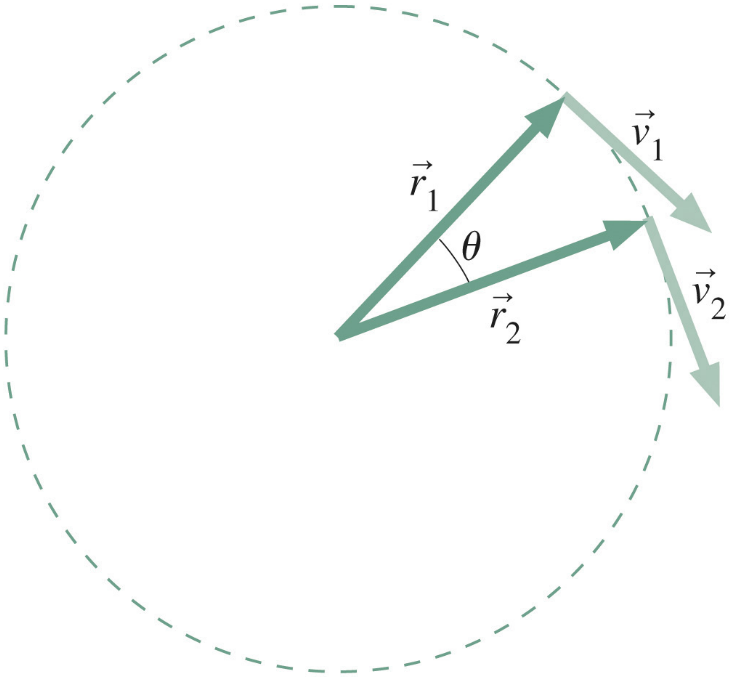
Chapter 6: Work, Energy and Power
Tuesday February 10th

- Finish Newton's laws and circular motion
- Energy
  - Work (definition)
  - Examples of work
- Work and Kinetic Energy
- Conservative and non-conservative forces
- Work and Potential Energy
- Conservation of Energy
- As usual – *i*clicker, examples and demonstrations

Reading: up to page 88 in the text book (Ch. 6)

Newton's 2nd law and uniform circular motion



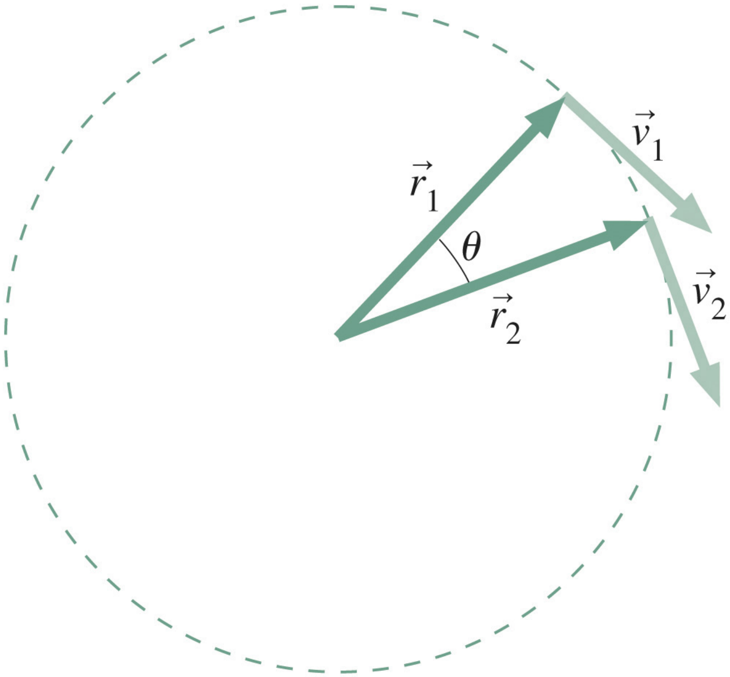
- Although the speed, v, does not change, the direction of the motion does, *i.e.*, the velocity, which is a vector, does change.
- Thus, there is an acceleration associated with the motion.
- We call this a centripetal acceleration.

Centripetal acceleration:

$$a_c = \frac{v^2}{r} \qquad \text{(uniform circular motion)}$$

- A vector that is always directed towards the center of the circular motion, i.e., it's direction changes constantly.

Newton's 2nd law and uniform circular motion



- Although the speed, v, does not change, the direction of the motion does, *i.e.*, the velocity, which is a vector, does change.
- Thus, there is an acceleration associated with the motion.
- We call this a centripetal acceleration.

Centripetal force:

$$F_c = ma_c = m\frac{v^2}{r} \quad \text{(uniform circular motion)}$$

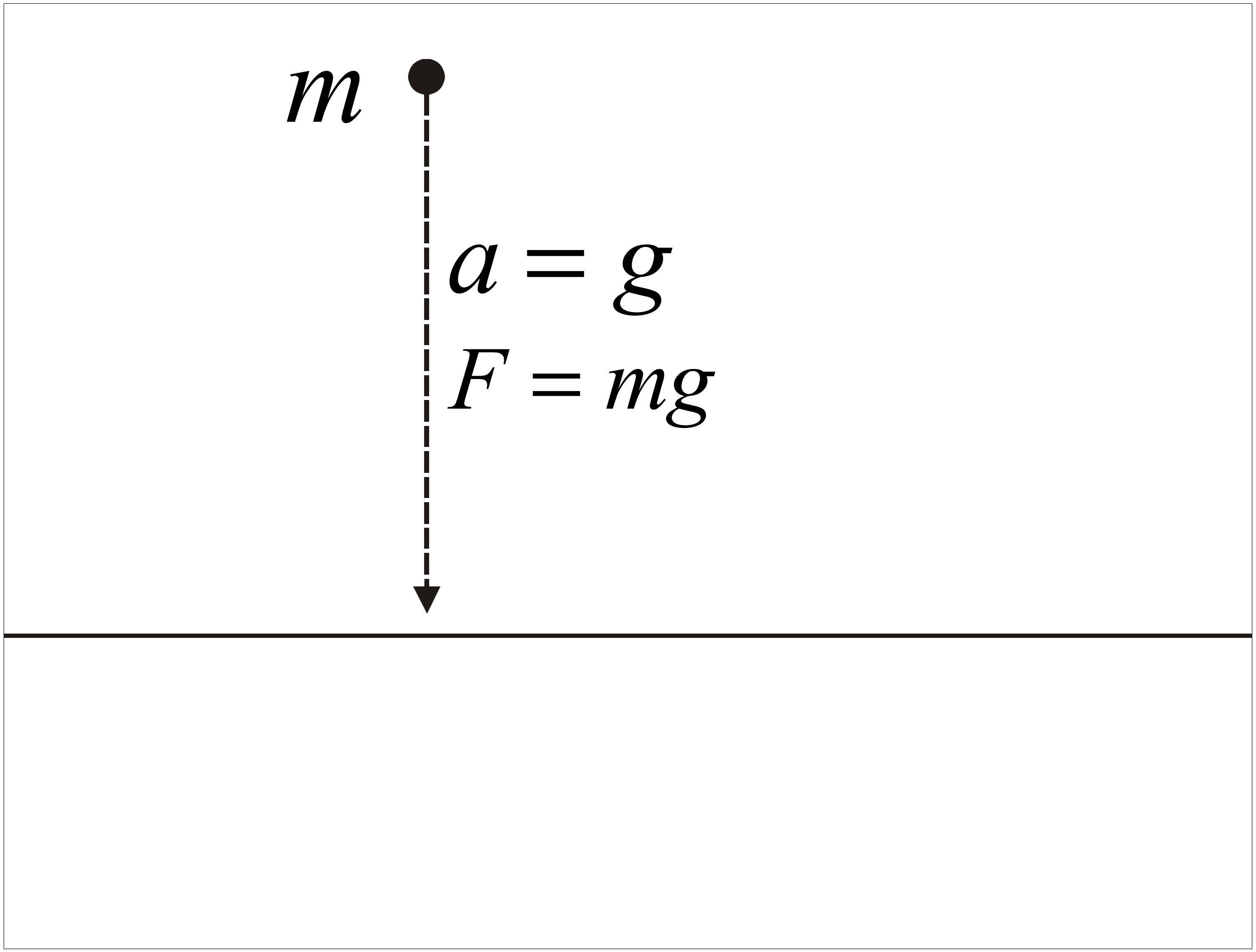
Period: $T = \dfrac{2\pi r}{v}$ (sec)   Frequency: $f = \dfrac{1}{T} = \dfrac{1}{2\pi}\dfrac{v}{r}$ (sec^{-1})

Newton's 2nd law and uniform circular motion

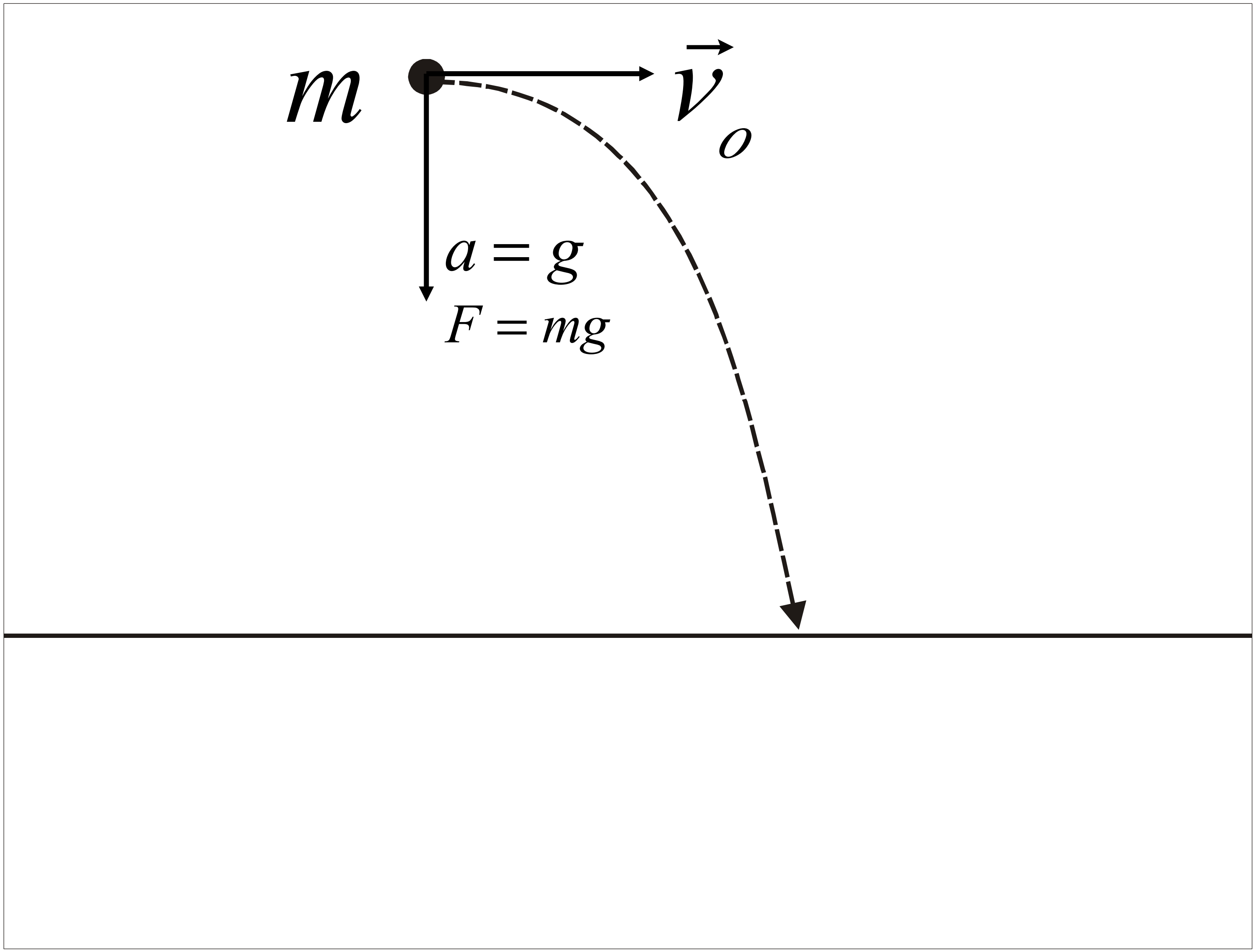
The vectors $\vec{a}, \vec{F}, \vec{v}$ and $\vec{r}$ are constantly changing

- The magnitudes a, F, v and r are constants of the motion.
- The frame in which the mass is moving is not inertial, *i.e.*, it is accelerating.
- Therefore, one cannot apply Newton's laws in the moving frame associated with the mass.
- However, we can apply Newton's laws from the stationary lab frame.
- Examples of centripetal forces: gravity on an orbiting body; the tension in a string when you swirl a mass in around in a circle; friction between a car's tires and the racetrack as a racing car makes a tight turn....

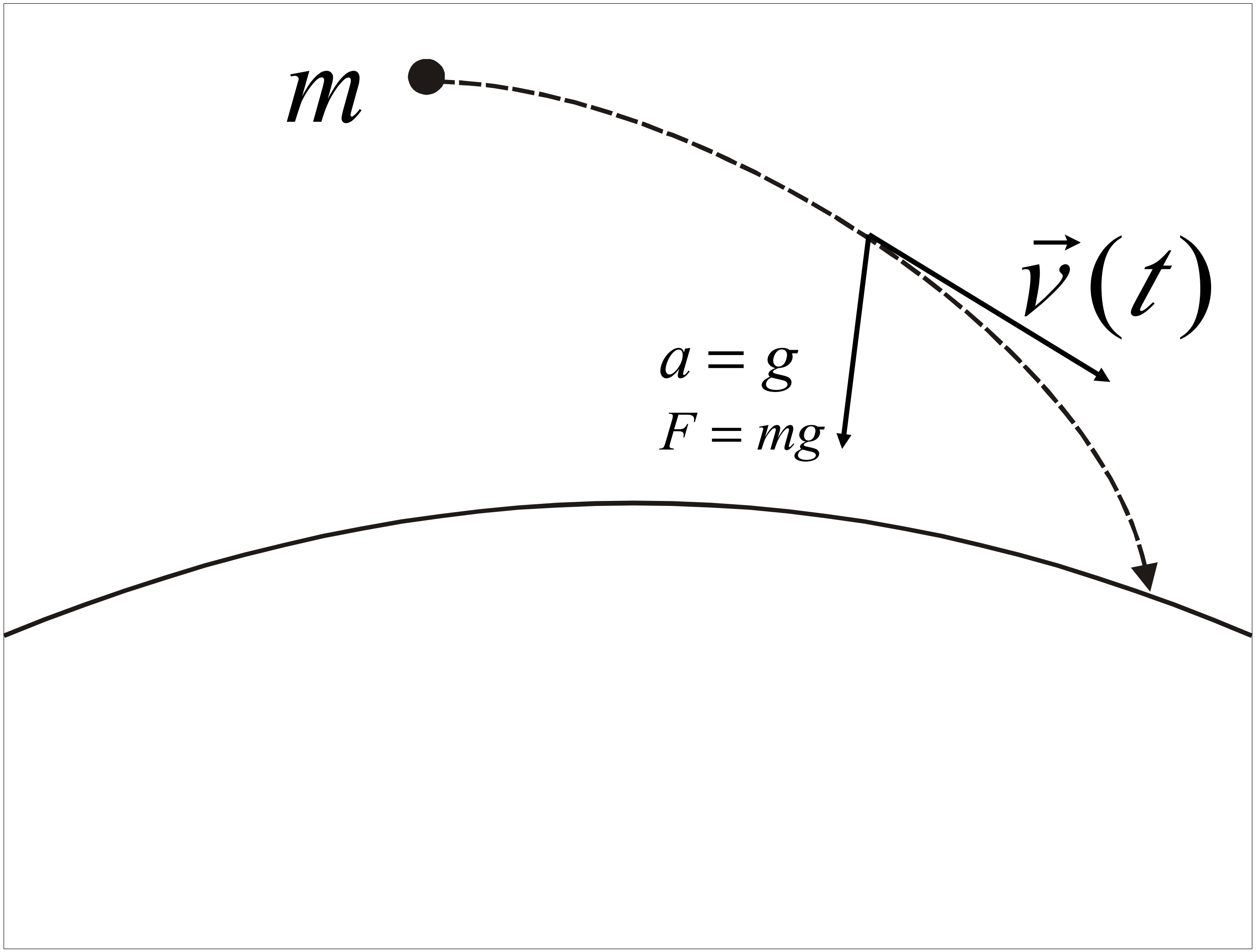
So why do you appear weightless in orbit?



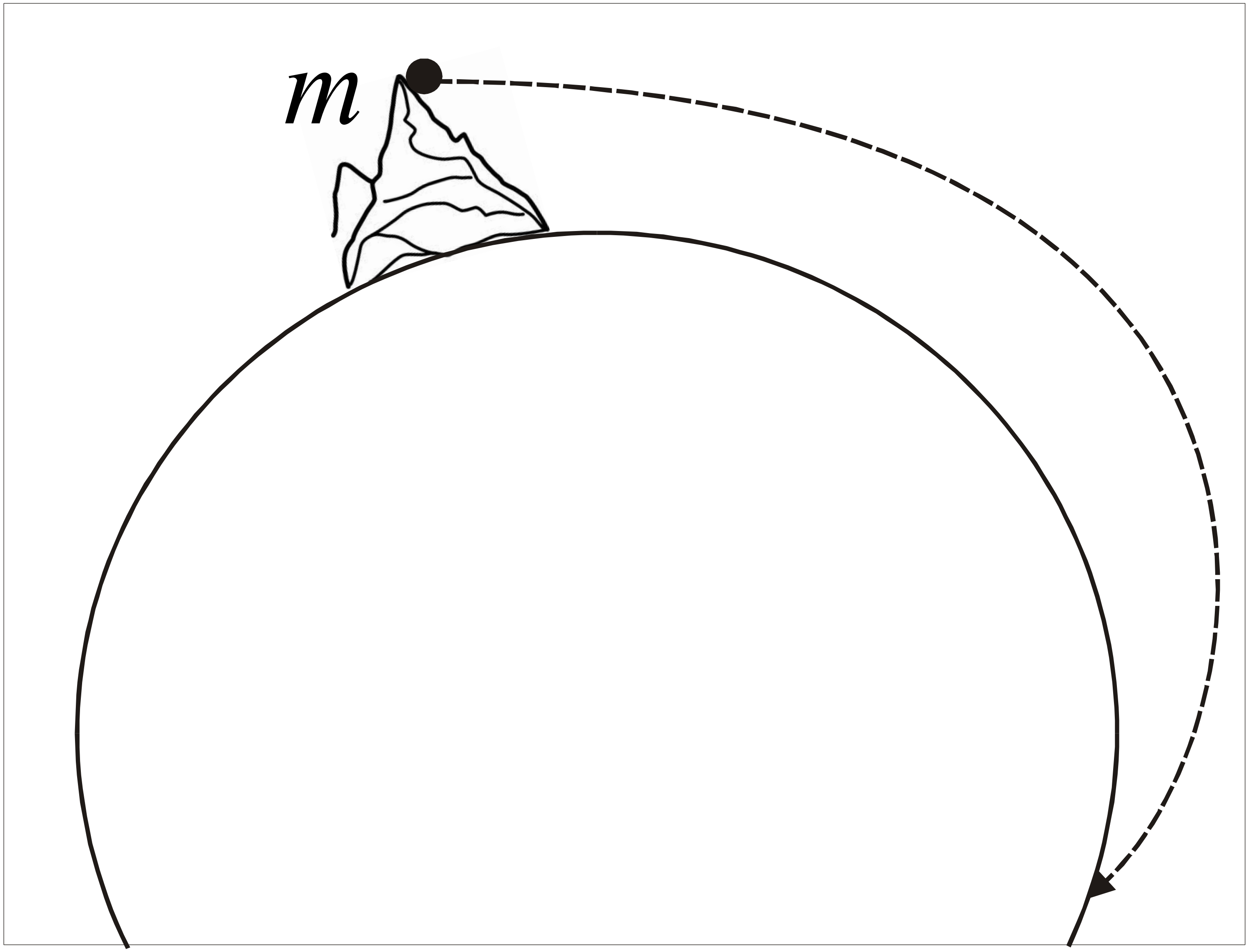
So why do you appear weightless in orbit?



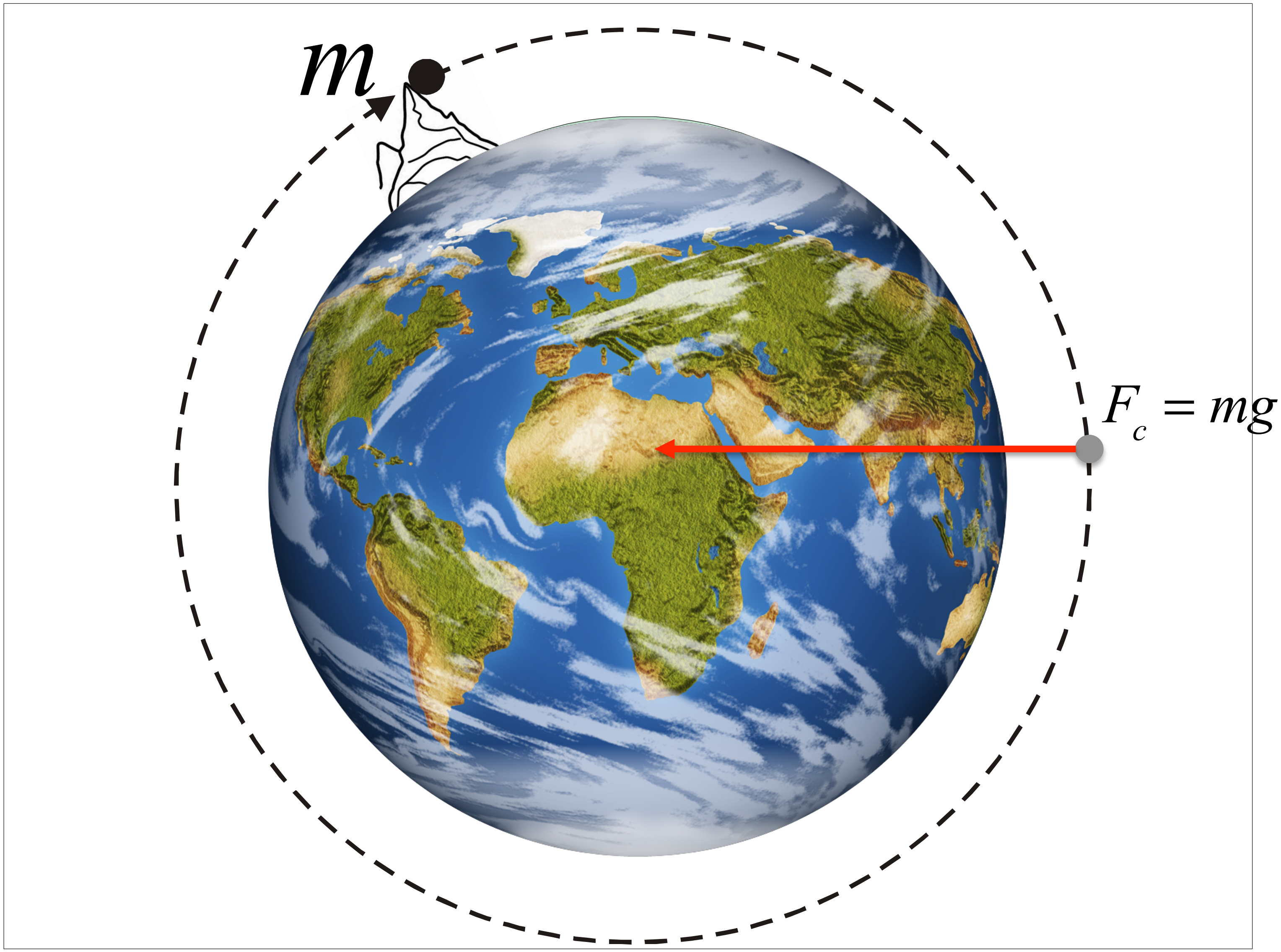
So why do you appear weightless in orbit?



So why do you appear weightless in orbit?

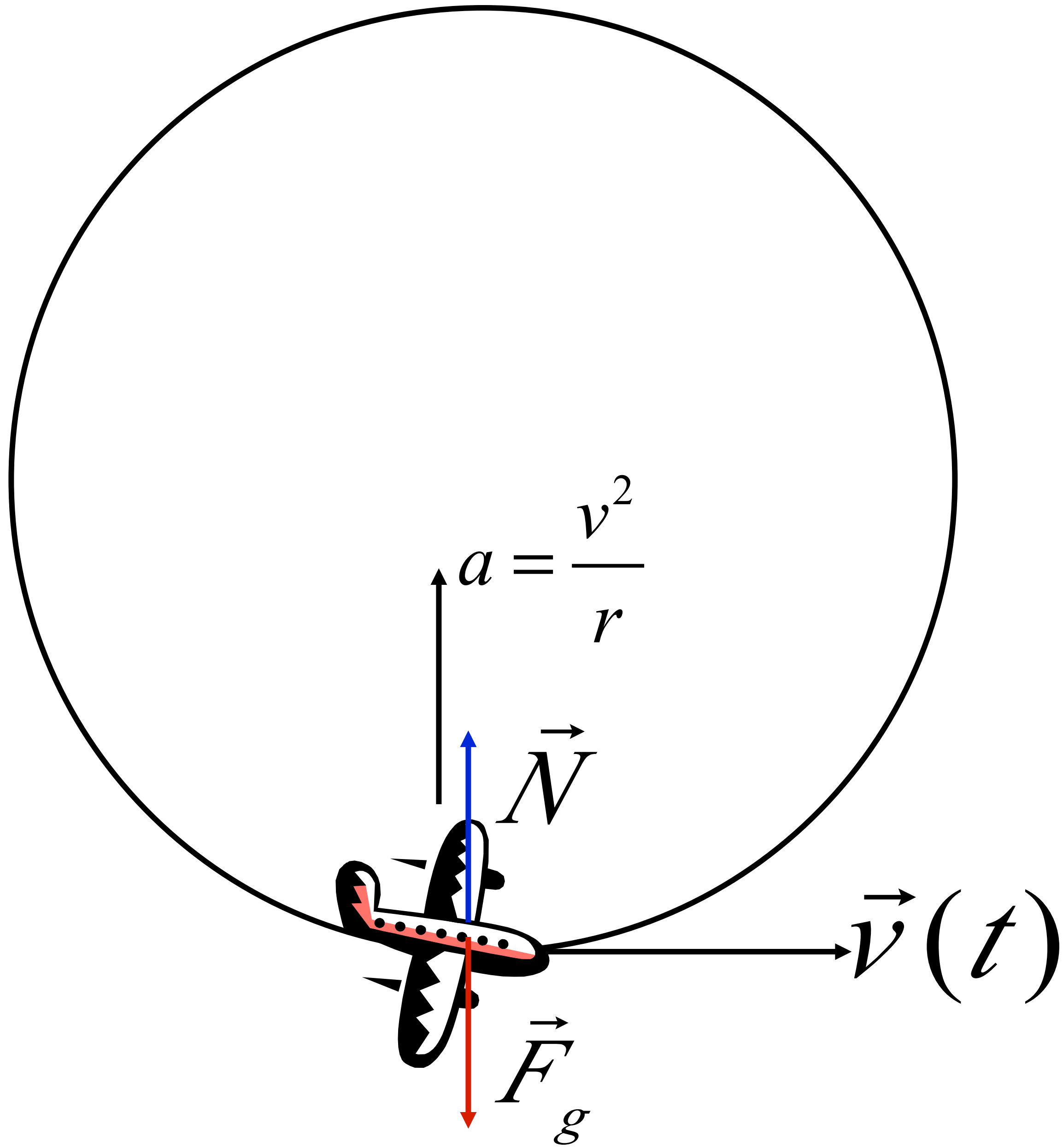


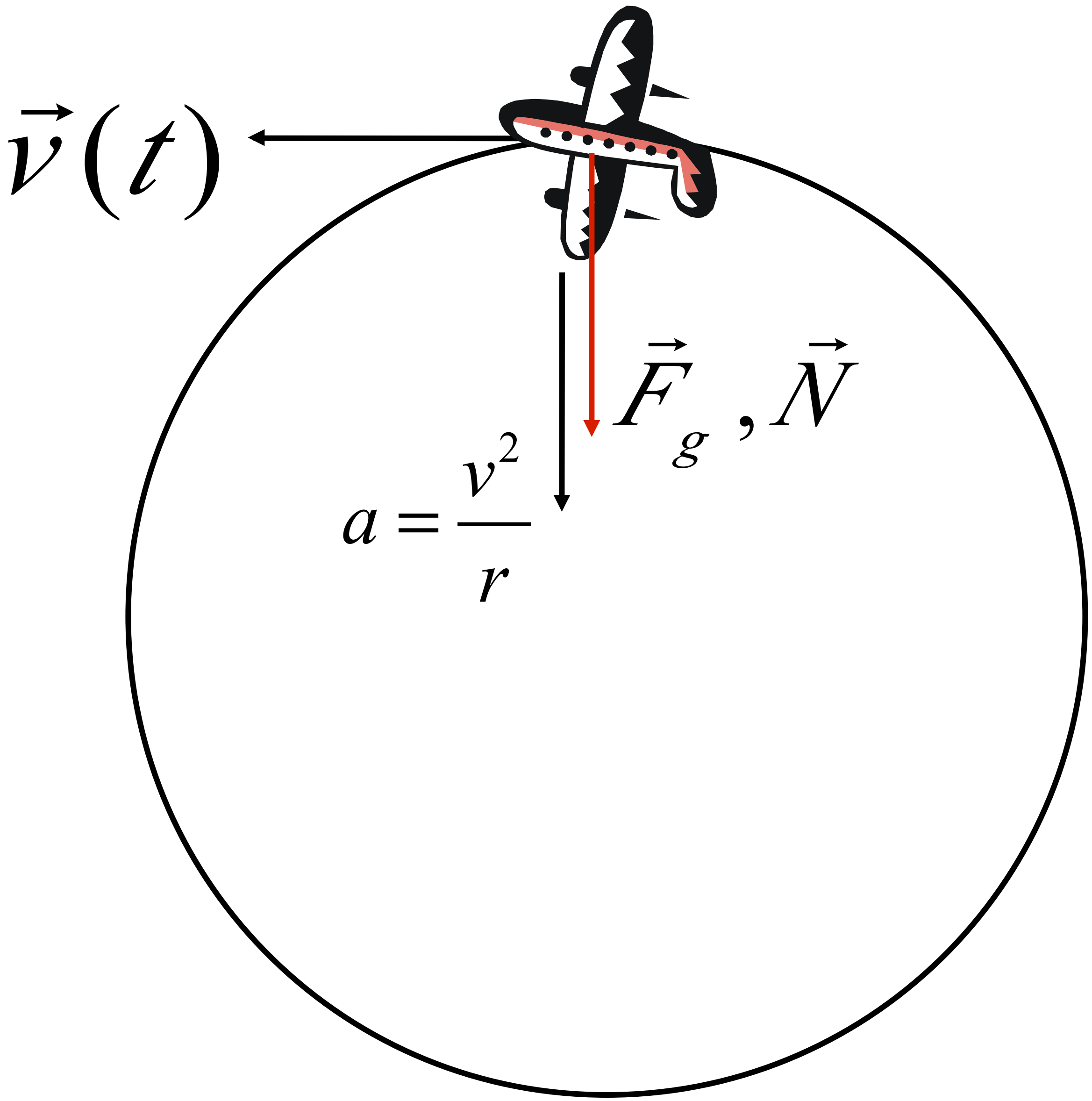
So why do you appear weightless in orbit?



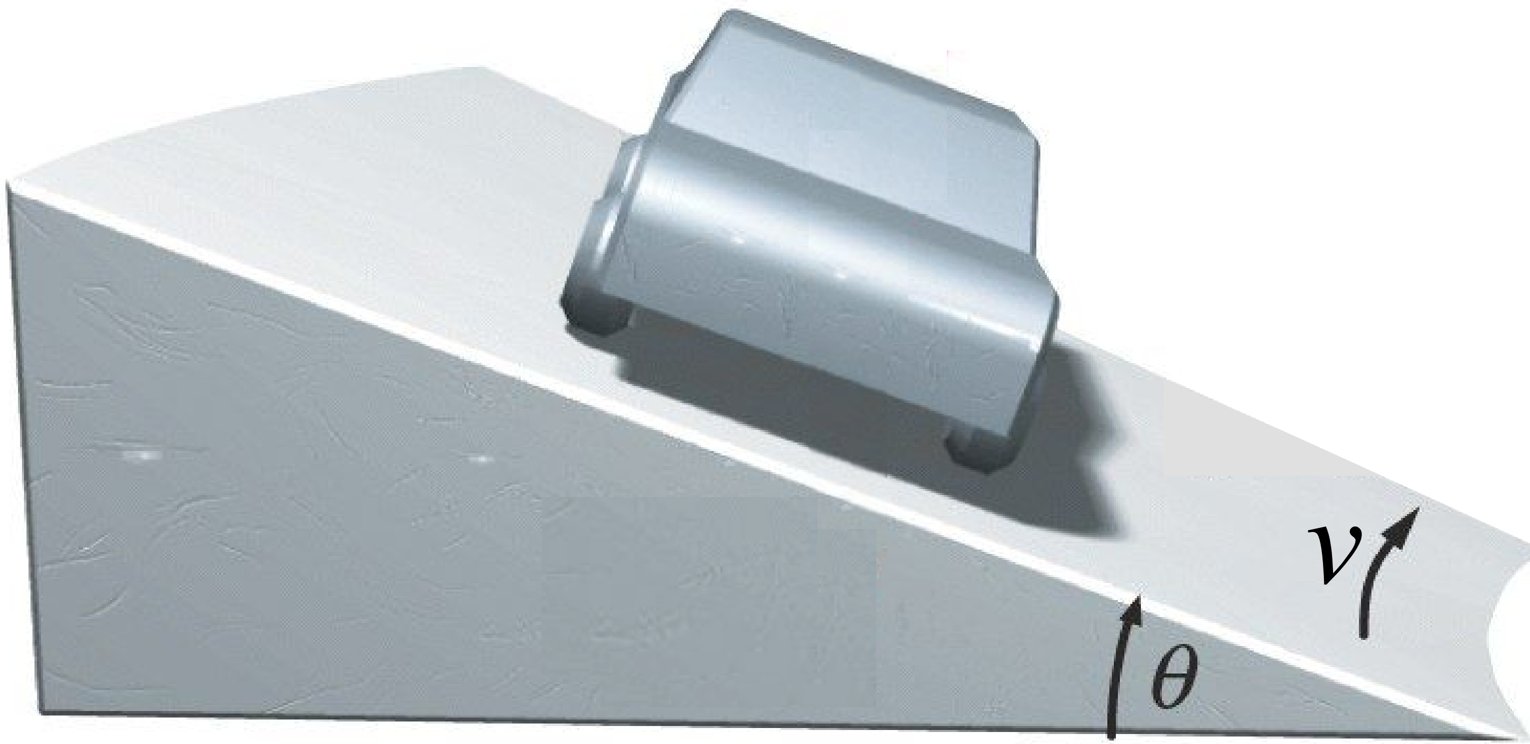
You are in constant free-fall!

Looping the loop

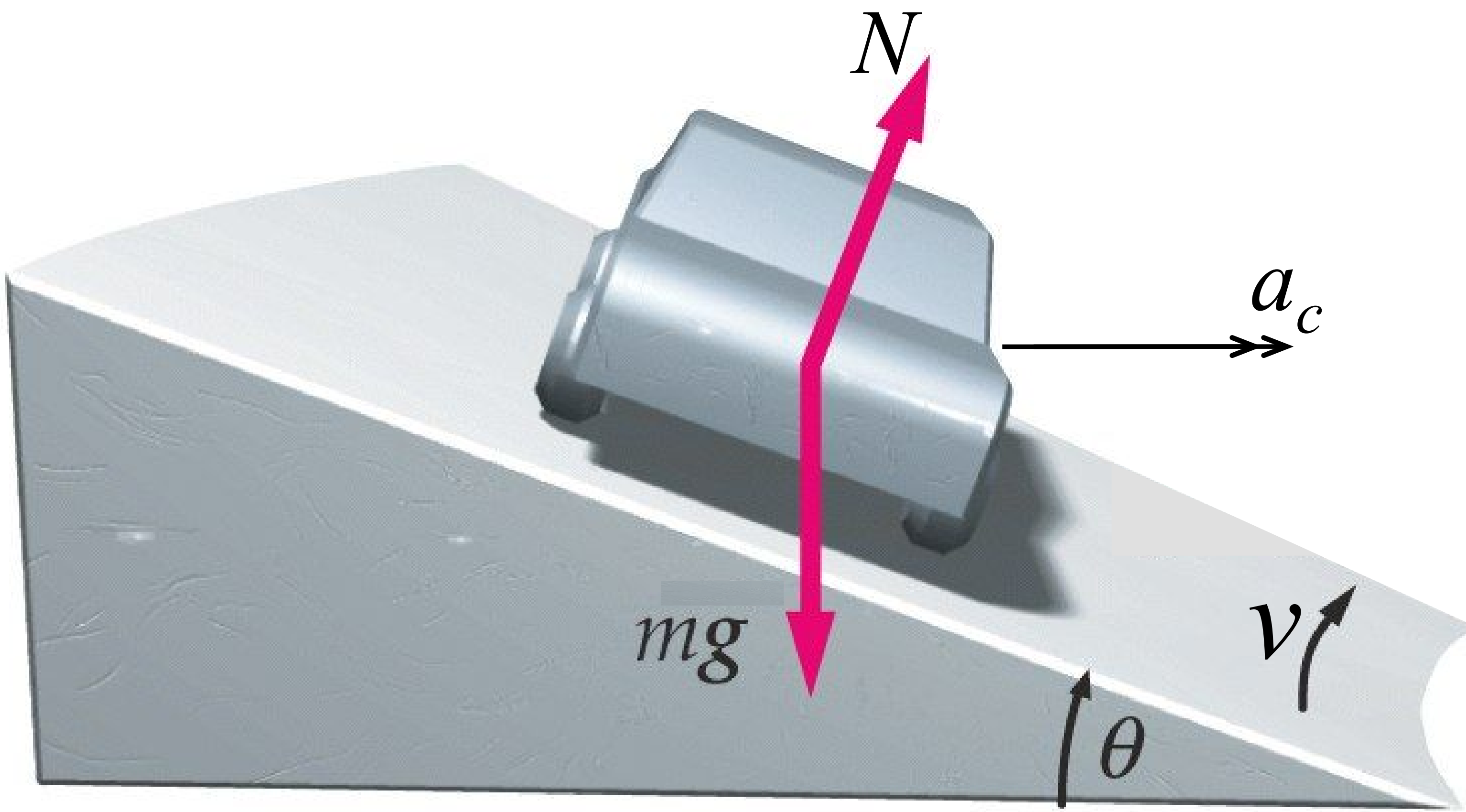



$\vec{v}(t)$
$\vec{F}_g$, $\vec{N}$
$a = \frac{v^2}{r}$

Daytona 500: the racetrack is covered in ice (!), so the physicist cannot rely on friction to prevent him/her from sliding off. How is it that he/she can continue the race?



Daytona 500: the racetrack is covered in ice (!), so the physicist cannot rely on friction to prevent him/her from sliding off. How is it that he/she can continue the race?



Energy

- Energy is a scalar* quantity (a number) that we associate with a system of objects, *e.g.*, planets orbiting a sun, masses attached to springs, electrons bound to nuclei, *etc.*
- Forms of energy: **kinetic**, **chemical**, **nuclear**, **thermal**, **electrostatic**, **gravitational**....
- It turns out that energy possesses a fundamental characteristic which makes it very useful for solving problems in physics: ****Energy is ALWAYS conserved****

Kinetic energy K is energy associated with the state of motion of an object. The faster an object moves, the greater its kinetic energy.

Potential energy U represents stored energy, e.g., in a spring. It can be released later as kinetic energy.

*This can make certain kinds of problem much easier to solve mathematically.

Work - Definition

Work W is the energy transferred to or from an object by means of a force acting on the object. Energy transferred to the object is positive work, and energy transferred from the object is negative work.

- If you accelerate an object to a greater speed by applying a force on the object, you increase its kinetic energy K; you performed work on the object.
- Similarly, if you decelerate an object, you decrease its kinetic energy; in this situation, the object actually did work on you (equivalent to you doing negative work).

Work - Definition

Work W is the energy transferred to or from an object by means of a force acting on the object. Energy transferred to the object is positive work, and energy transferred from the object is negative work.

- If an object moves in response to your application of a force, you have performed work.
- The further it moves under the influence of your force, the more work you perform.
- There are only two relevant variables in one dimension:

the force, F_x, and the displacement, Δx.

Work - Definition

Work W is the energy transferred to or from an object by means of a force acting on the object. Energy transferred to the object is positive work, and energy transferred from the object is negative work.

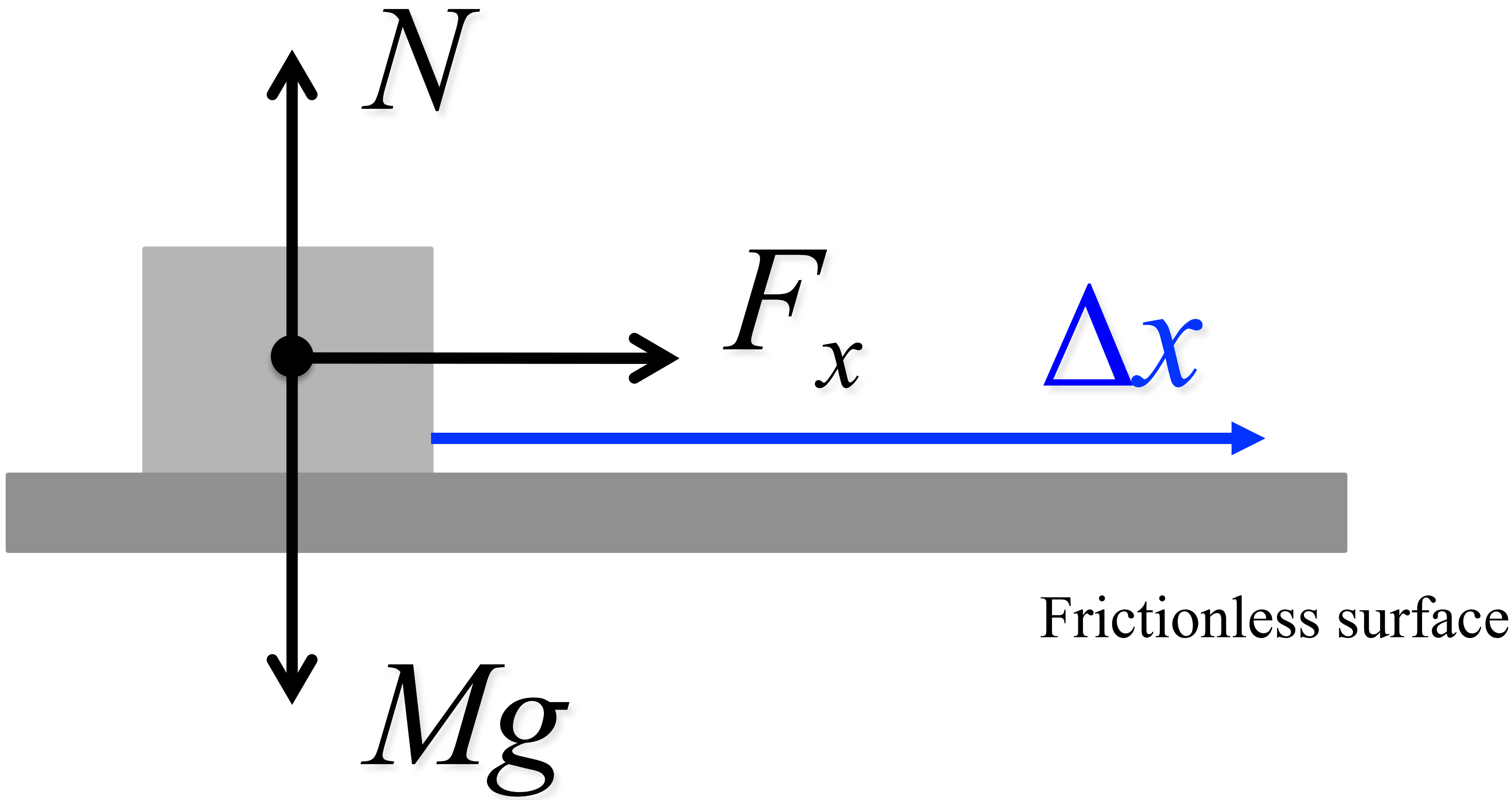
- There are only two relevant variables in one dimension: the force, F_x, and the displacement, Δx.

Definition: $W = F_x \Delta x$ [Units: N.m or Joule (J)]

F_x is the component of the force in the direction of the object's motion, and Δx is its displacement.

- Examples:
  - Pushing furniture across a room;
  - Carrying boxes up to your attic.

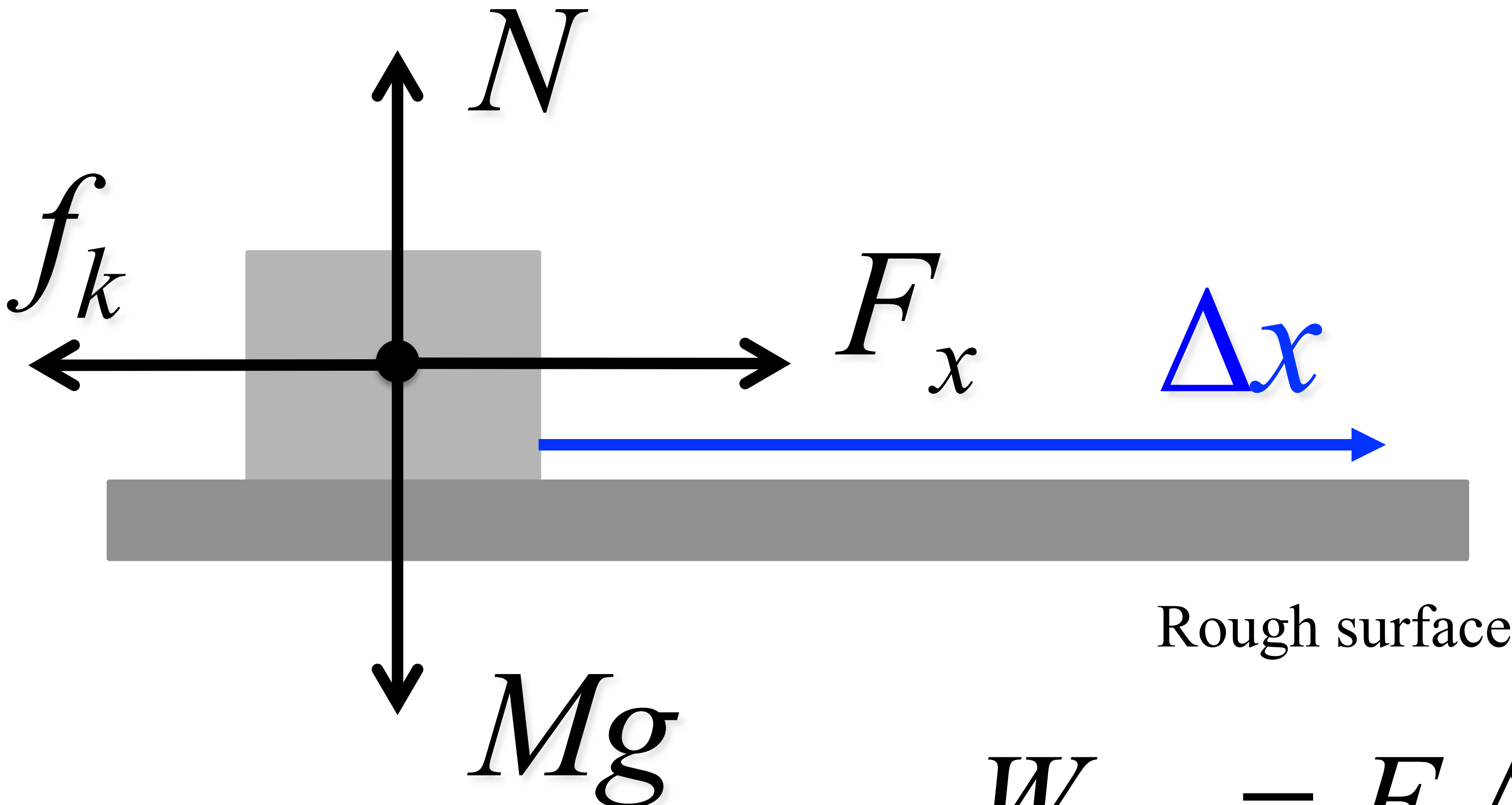
Work - Examples



$$W = F_x \Delta x$$

Work - Examples

These two seemingly similar examples are, in fact, quite different

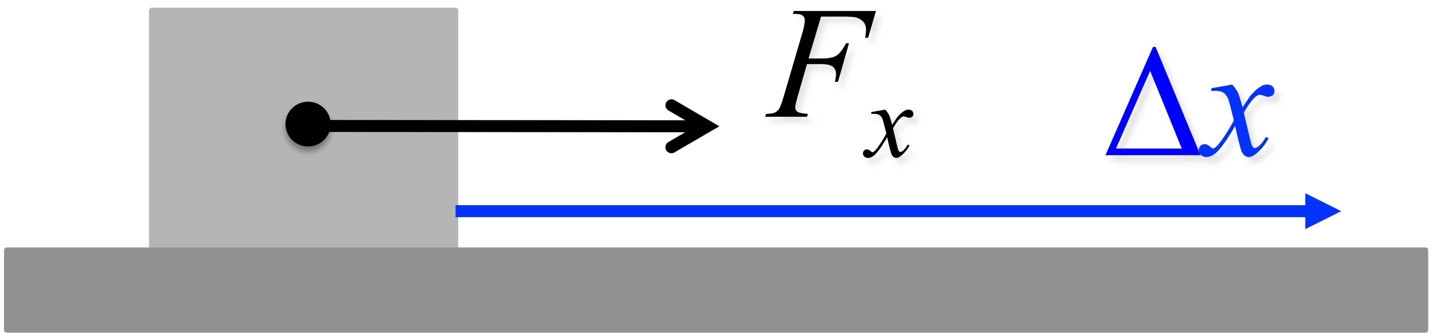


$$W_{\text{Pull}} = F_x \Delta x$$

$$W_{\text{fric.}} = -f_k \Delta x$$

Work - Examples

$$v_f^2 = v_i^2 + 2a_x\Delta x$$



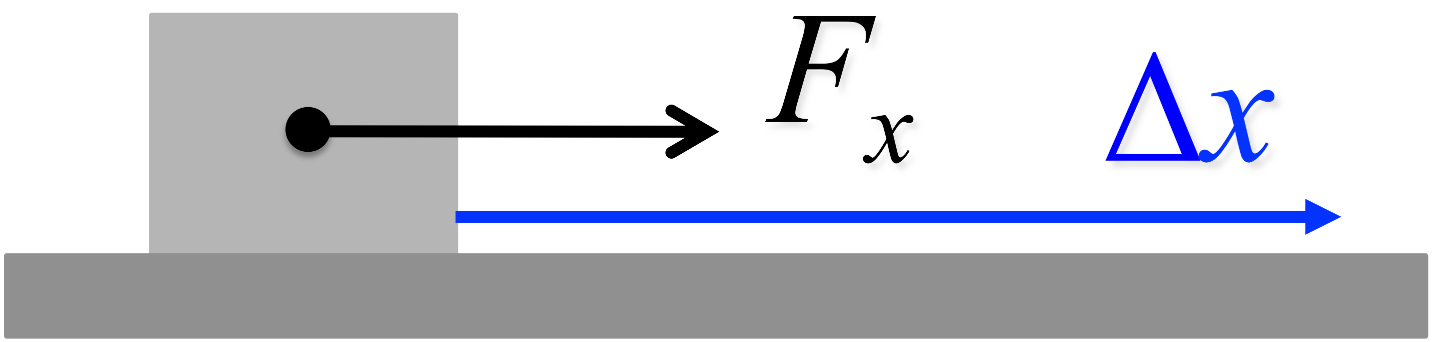
Frictionless surface

$$\tfrac{1}{2}mv_f^2 - \tfrac{1}{2}mv_i^2 = \tfrac{1}{2}m \times 2a_x\Delta x$$

$$\Delta K = K_f - K_i = ma_x\Delta x = F_x\Delta x = W$$

Kinetic Energy - Definition

$$K = \tfrac{1}{2}mv^2$$



Frictionless surface

$$\tfrac{1}{2}mv_f^2 - \tfrac{1}{2}mv_i^2 = \tfrac{1}{2}m \times 2a_x\Delta x$$

$$\Delta K = K_f - K_i = ma_x\Delta x = F_x\Delta x = W$$

Work-Kinetic Energy Theorem

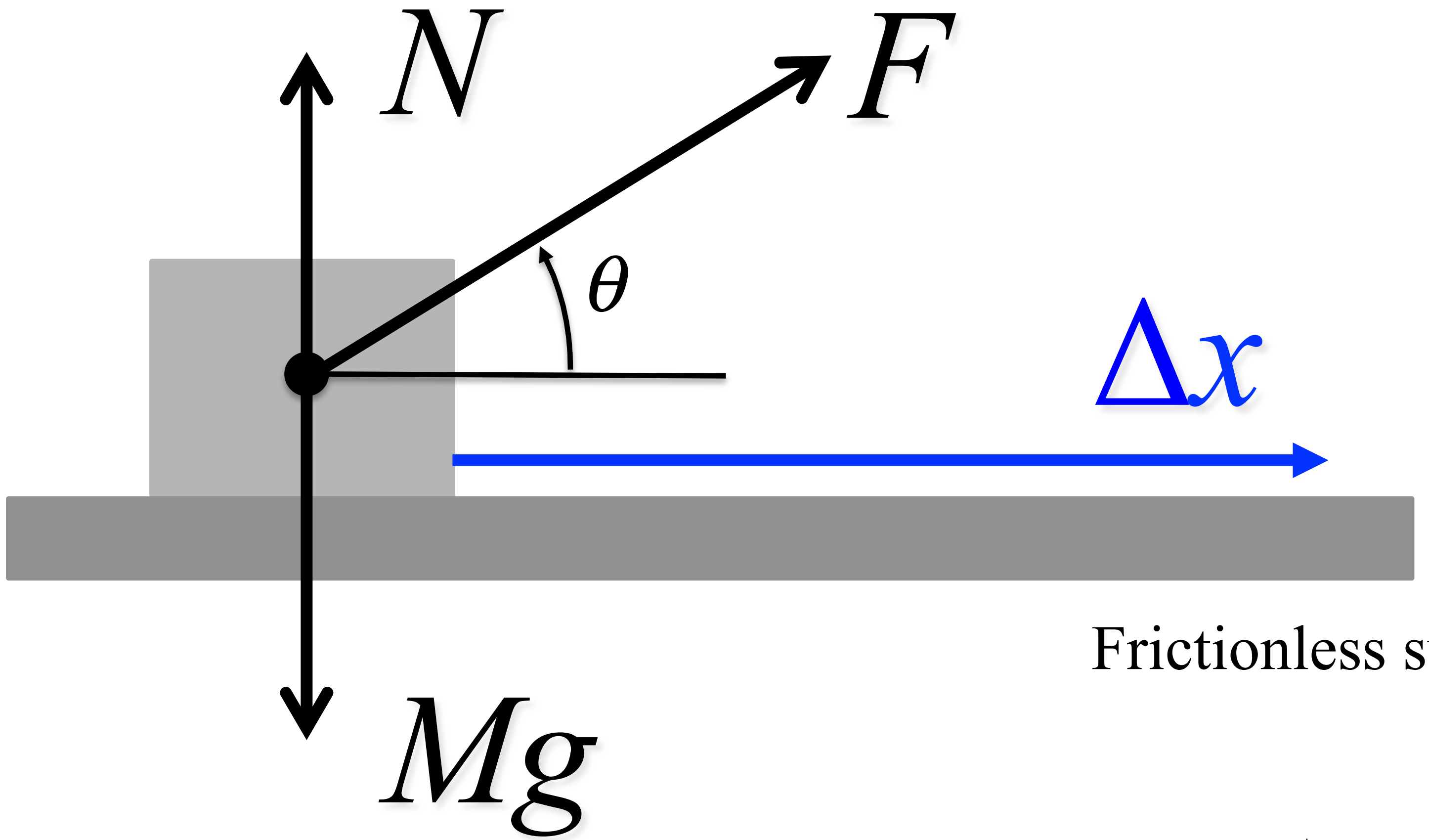
$$\Delta K = K_f - K_i = W_{\text{net}}$$

$$\begin{pmatrix}\text{change in the kinetic} \\ \text{energy of a particle}\end{pmatrix} = \begin{pmatrix}\text{net work done on} \\ \text{the particle}\end{pmatrix}$$

$$K_f = K_i + W_{\text{net}}$$

$$\begin{pmatrix}\text{kinetic energy after} \\ \text{the net work is done}\end{pmatrix} = \begin{pmatrix}\text{kinetic energy} \\ \text{before the net work}\end{pmatrix} + \begin{pmatrix}\text{the net} \\ \text{work done}\end{pmatrix}$$

More on Work

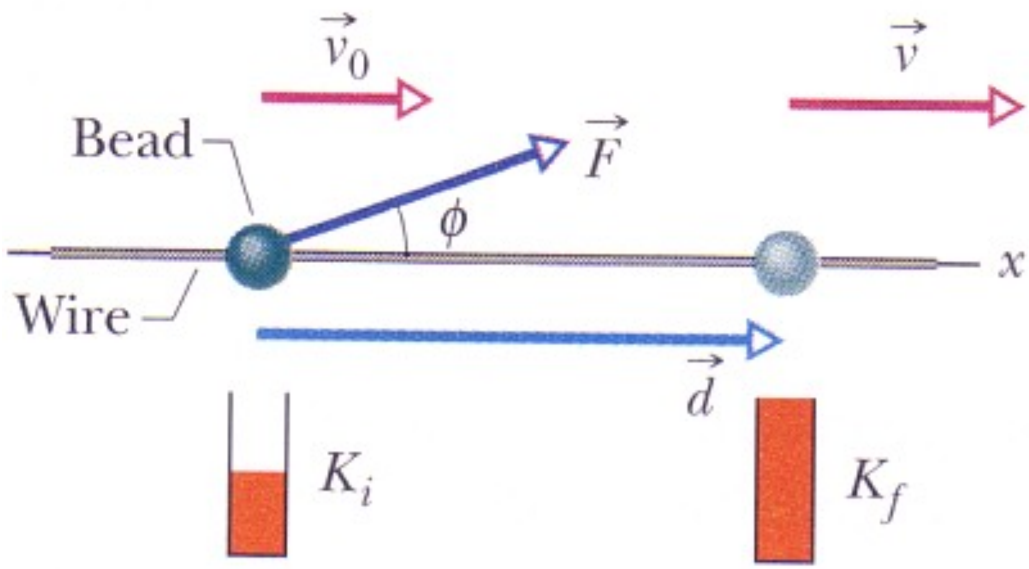


Frictionless surface

$$W = F_x \Delta x$$
$$= F\cos\theta \cdot \Delta x$$

More on Work

To calculate the **work** done on an object by a force during a displacement, we use only the force component along the object's displacement. The force component perpendicular to the displacement does zero work



$$F_x = F\cos\phi$$

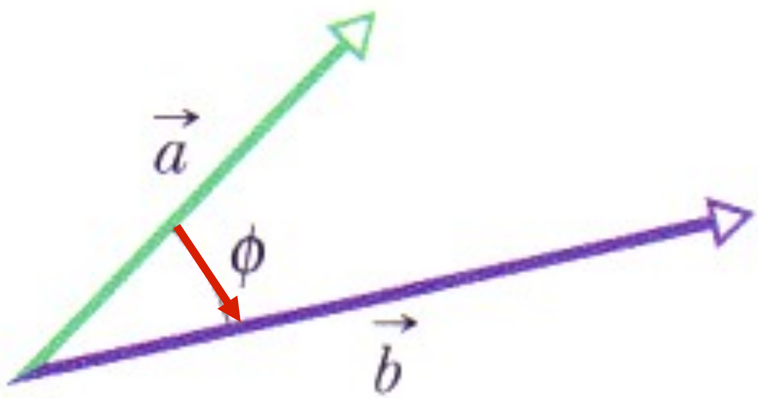
$$W = Fd\cos\phi$$

$$W = \vec{F}\cdot\vec{d}$$

- Caution: for all the equations we have derived so far, the force must be constant, and the object must be rigid.
- I will discuss variable forces later.

The scalar product, or dot product

$$\vec{a} \cdot \vec{b} = ab\cos\phi$$



$$(a)(b\cos\phi) = (a\cos\phi)(b)$$

$$\cos\phi = \cos(-\phi)$$

$$\Rightarrow \vec{a} \cdot \vec{b} = \vec{b} \cdot \vec{a}$$

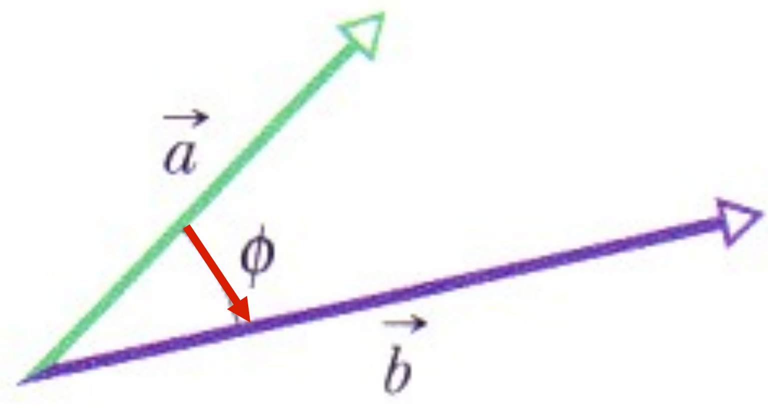
- The scalar product represents the product of the magnitude of one vector and the component of the second vector along the direction of the first

$$\text{If } \phi = 0^{\circ}\text{, then } \vec{a} \cdot \vec{b} = ab$$

$$\text{If } \phi = 90^{\circ}\text{, then } \vec{a} \cdot \vec{b} = 0$$

The scalar product, or dot product

$$\vec{a} \cdot \vec{b} = ab\cos\phi$$



$$(a)(b\cos\phi) = (a\cos\phi)(b)$$

$$\cos\phi = \cos(-\phi)$$

$$\Rightarrow \vec{a} \cdot \vec{b} = \vec{b} \cdot \vec{a}$$

- The scalar product becomes relevant in Chapter 6 (pages 88 and 97) when considering work and power.
- There is also a vector product, or cross product, which becomes relevant in Chapter 11 (pages 176-178). I save discussion of this until later in the semester.
- See also Appendix A.