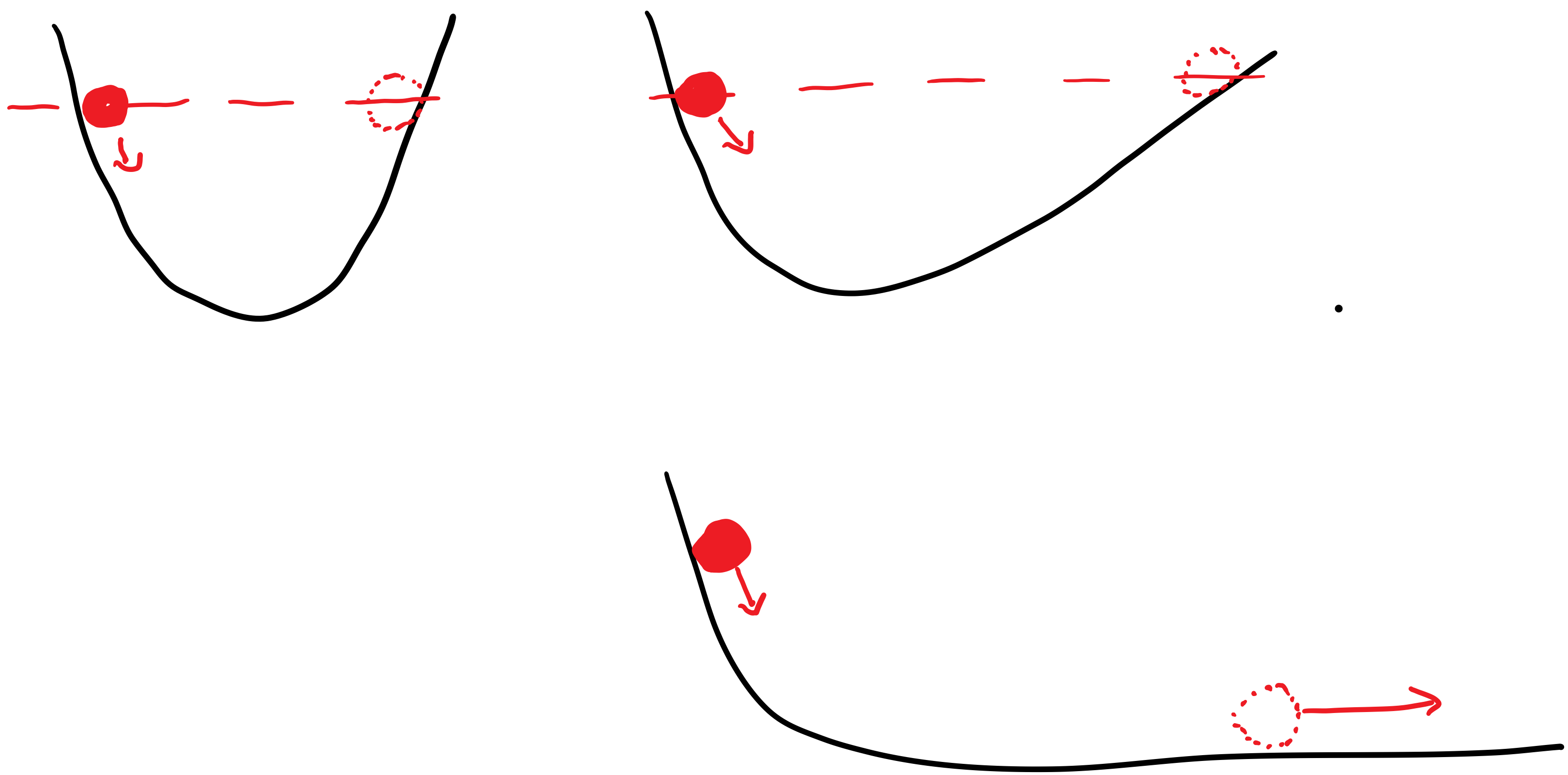
Lecture 5: Newton's 1st and 2nd Laws

- Newton's 1st and 2nd Law
- Inertia
- Relationship between forces and acceleration
- Procedure for solving force problems

What is the “natural” state of an object left to itself?

Aristotle: to be at rest.

Galileo: to be in uniform motion with constant velocity.



Newton's 1st Law – Law of Inertia

Every body continues in its state of rest or of uniform speed in a straight line unless acted on by a nonzero force.

If no external force acts on an object, its velocity remains constant: $\Sigma\vec{F} = 0 \implies \vec{v} = constant$ *

* Remember that **velocity** is a VECTOR, and has both direction and magnitude

Newton's 1st Law applied to cats

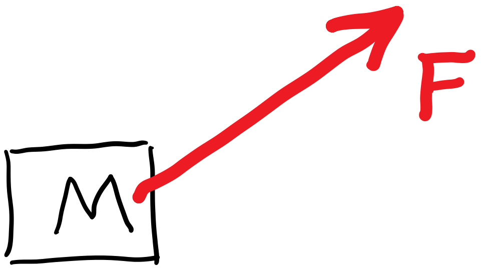
A cat at rest remains at rest unless acted on by a nonzero force.

Examples for forces

- Gravity (weight)
- Spring force
- Tension (ball held by rope)
- Friction
- Push/Pull
- Electromagnetic forces

A force….

...is a push or pull
…acts on a object
…is a vector and has magnitude and direction



Stop to Think: Discussion Question

You throw a small ball straight up. Disregarding any effect of air resistance, what forces are acting on the ball until it returns to the ground?

A) a constant downward force of gravity only.

B) its weight vertically downward along with a steadily decreasing upward force.

C) a steadily decreasing upward force from the moment it leaves the hand until it reaches the highest point, beyond which there is a steadily increasing downward force of gravity.

A force….

...is a push or pull
…acts on a object
…is a vector and has magnitude and direction
…requires an agent
…is either a contact force or a long-range force (such as gravity)

Changes in velocity

If $\vec{v} = constant$ in magnitude and direction
$\Longrightarrow \vec{a} = 0$

Changes in velocity such as

- Stopping (or starting) an object
- Changing direction of motion
- Increasing/decreasing speed

require force.

Inertia

Observation:

Objects with greater weight are harder to accelerate.

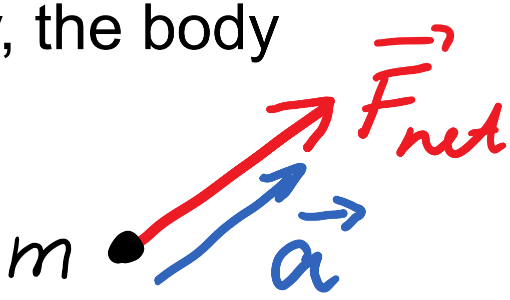
In deep space: no gravity, so no weight.
But objects still have intrinsic resistance to acceleration.

This resistance to changes in motion is called **inertia**, and the quantity of resistance is called **mass** m.

Newton's 2nd Law

If a net external force acts on a body, the body accelerates.

$$\vec{a} = \frac{\vec{F}_{net}}{m} = \frac{\Sigma\vec{F}}{m}$$



$$\Sigma\vec{F} = m\vec{a}$$

*for object
with constant mass

Unit: $kg\,\frac{m}{s^2} = N$ Newton

Component version of Newton's 2nd Law

$$\vec{F}_{net} = \Sigma\vec{F} = m\vec{a} \quad *$$

*Net force also sometimes called resultant or total force

$$F_{net,x}\hat{\imath} + F_{net,y}\hat{\jmath} = \Sigma F_x\hat{\imath} + \Sigma F_y\hat{\jmath} = ma_x\hat{\imath} + ma_y\hat{\jmath}$$

$$\Sigma F_x = ma_x$$
$$\Sigma F_y = ma_y$$

Because the axes are orthogonal, we can separately equate the *x*-components and the *y*-components.

Weight force

Earth's gravitational field exerts a force on objects.
At Earth's surface:

$$\vec{F}_{grav} = m\overrightarrow{g}$$

$\overrightarrow{g} = (g, down)$ with magnitude $g = 9.8$ m/s^2

Gravitational force on an object is called **weight**.

$$\overrightarrow{W} = (mg, down)$$

m in weight and m in Newton's second law
are the same! Inertial mass = gravitational mass

Object in free fall

If gravitational force is the only force acting on object:

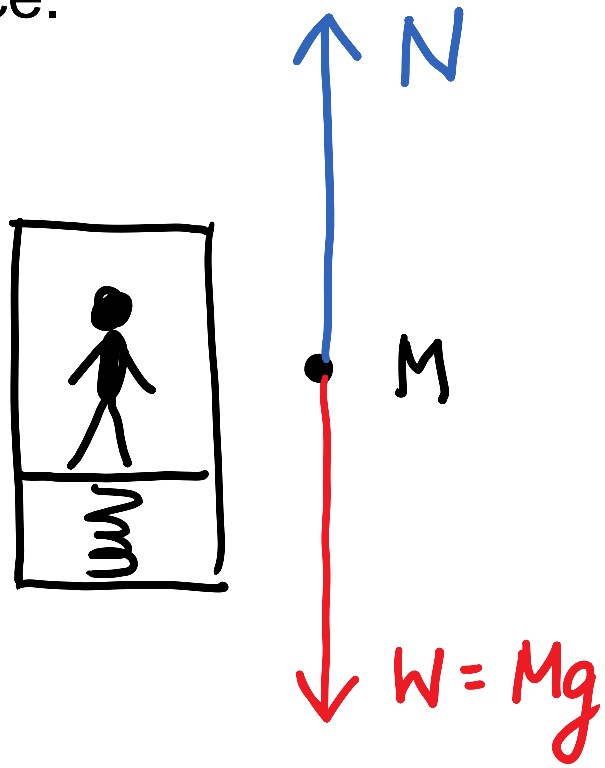
$$\vec{F}_{grav} = m\overrightarrow{g} = m\overrightarrow{a} \quad \Longrightarrow \overrightarrow{a} = \overrightarrow{g}$$

Free fall acceleration independent of mass.

But:
Even if object is not in free fall, the force of gravity acts on it.

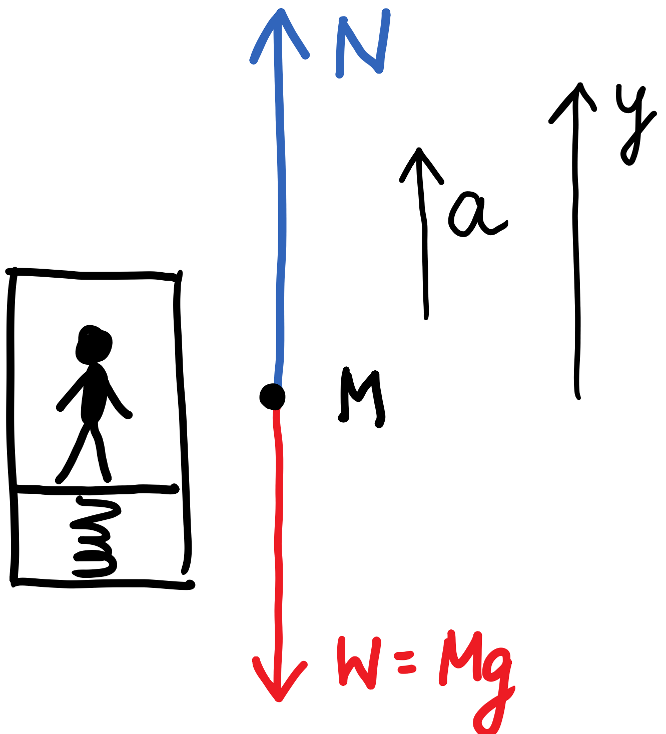
Can we feel gravity?

We can not feel the gravitational force.
We can feel a normal force from the floor or seat.
Spring scale shows normal force.
If $a = 0$: $N = Mg$



Apparent weight

In an elevator that accelerates upwards:



$$\Sigma F_y = N_y + W_y = Ma_y$$
$$(+N) + (-Mg) = M(+a)$$

$N = M(g + a)$
Apparent weight
more than real weight.
Feels "heavier"

If elevator accelerates downwards: $N = M(g - a)$

If cable breaks: $a_y = -g, N = 0$ no sensation of weight*

*but very bad upon impact

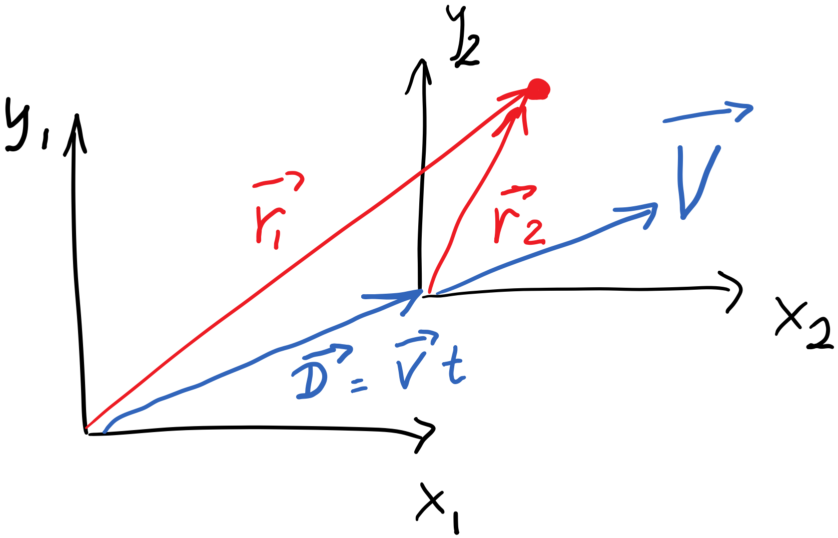
Inertial Reference Frames

An inertial reference frame is a coordinate system in which Newton's laws are valid.

Airplane cruising at constant velocity:
A ball on the floor remains at rest relative to the airplane → the plane is an inertial reference frame

Airplane accelerating before take-off:
A ball on the floor rolls to the back of the plane.
No horizontal force acts on the ball, but it accelerates in the plane's coordinate system!
→ the plane is not an inertial reference frame

Galilei Transformation



Coordinate system 2 moving at constant $\vec{V}$ with respect to coordinate system 1

$$\vec{r}_1 = \vec{r}_2 + \vec{D} = \vec{r}_1 + \vec{V}t$$

$$\frac{d}{dt} \downarrow$$

$$\vec{v}_1 = \vec{v}_2 + \vec{V}$$

$$\frac{d}{dt} \downarrow$$

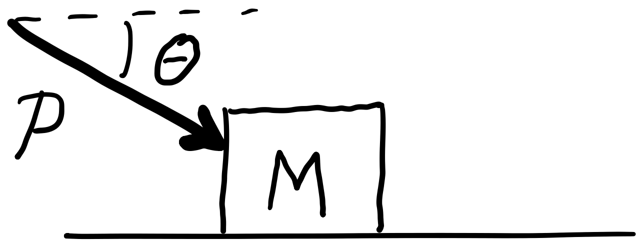
$$\vec{a}_1 = \vec{a}_2$$

$$m\vec{a}_1 = m\vec{a}_2 = \sum \vec{F}$$

Newton's Laws look the same!

Example

A worker pushes a crate of mass *M* on a level frictionless surface by applying a constant pushing force of magnitude *P* at an angle θ with respect to the horizontal, as shown in the figure.



Derive expressions for the acceleration of the crate and the magnitude of the normal force acting on the crate, in terms of relevant system parameters.

Summary of *Litany for Force Problems*

- Sketch
- Free-body diagram, including known or assumed acceleration vector. Label.
- x-y- coordinate system. Choose one of the axes to be in the direction of the known or assumed acceleration vector.
- Draw vector components.
- Starting equation $\Sigma F_x = ma_x$ or $\Sigma F_y = ma_y$
- Write out the sum of force components.
- Solve symbolically.