PHYS 225
Fundamentals of Physics: Mechanics

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Lecture 14: Gravity, weight and normal force

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Summary: Newton's three laws

- Newton's 1st law:
  - If $\vec{F}_{net} = 0$ on an object, then $\vec{a} = 0$ for the object, vice versa.

    If $\vec{a} = 0$, then, $\vec{F}_{net} = 0$
- Newton's 2nd law:
  - $\vec{F}_{net} = m\vec{a}$

    mass
- Newton's 3rd law:

  obj. A & obj. B
  - "For a force on A **by** B, there is an equal and opposite force on B **by** A":

$$\vec{F}_{AB} = -\vec{F}_{BA}$$

$\vec{F}_{AB}$ & $\vec{F}_{BA}$: Force pair

Chapter 5.2: Some particular forces

Learning goals for today

- Weight
- Force of gravity
- Normal force
- **Free body diagram** FBD

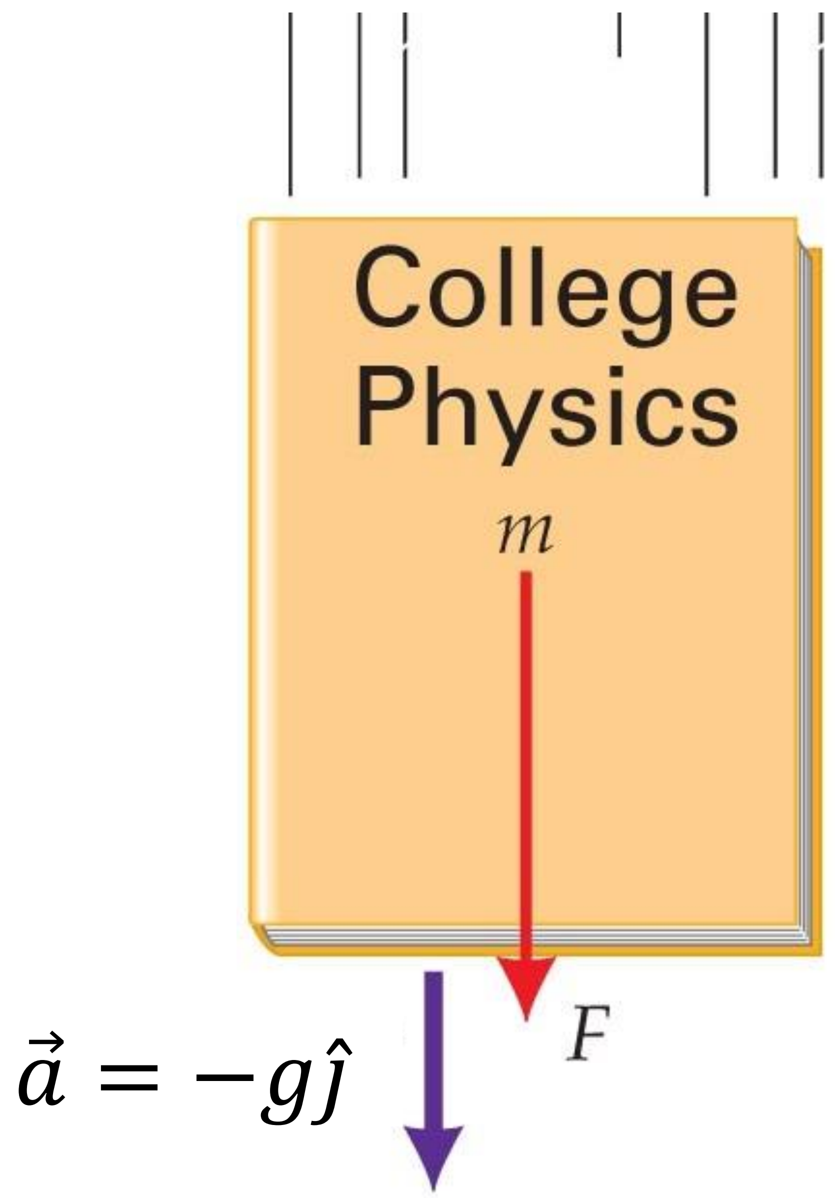
1. Weight

$+y$

$\hat{i}$ $\hat{j}$ $\hat{k}$

x y z

- Weight = force of gravity near earth's surface



$$\vec{F} = \underbrace{\vec{W}}_{\text{Weight}} = \underbrace{m\vec{a}_y}_{\text{Only if}} = -mg\hat{j}$$

Only if $\vec{W}$ is the only force on the obj.

g is typically 9.8 m/s^2 on earth's surface.

$$\boxed{\text{In general: } W = -mg\hat{j}}$$

Clicker question 1

$\uparrow y$

Given: $v_{10} = v_{20} = 0$, $\vec{a} = -g\hat{j}$, $\Delta y_1 = \Delta y_2 = -h$

Goal: t_1 ? t_2

Coin: 1

Feather: 2

Feather, penny dropped from rest and from same height. Which will land first **in a vacuum**?

A  lands first

B They land at the same time

C 

lands first

Free fall

$$\Delta y = v_{0y} t - \frac{1}{2} g t^2$$

$$\Delta y_1 = \underbrace{v_{10}}_{0} t - \frac{1}{2} g t_1^2$$

$$t_1 = \sqrt{-\frac{2\Delta y_1}{g}} = \sqrt{\frac{2h}{g}}$$

$$\Delta y_2 = v_{20} t - \frac{1}{2} g t_2^2$$

$$t_2 = \sqrt{\frac{2h}{g}}$$

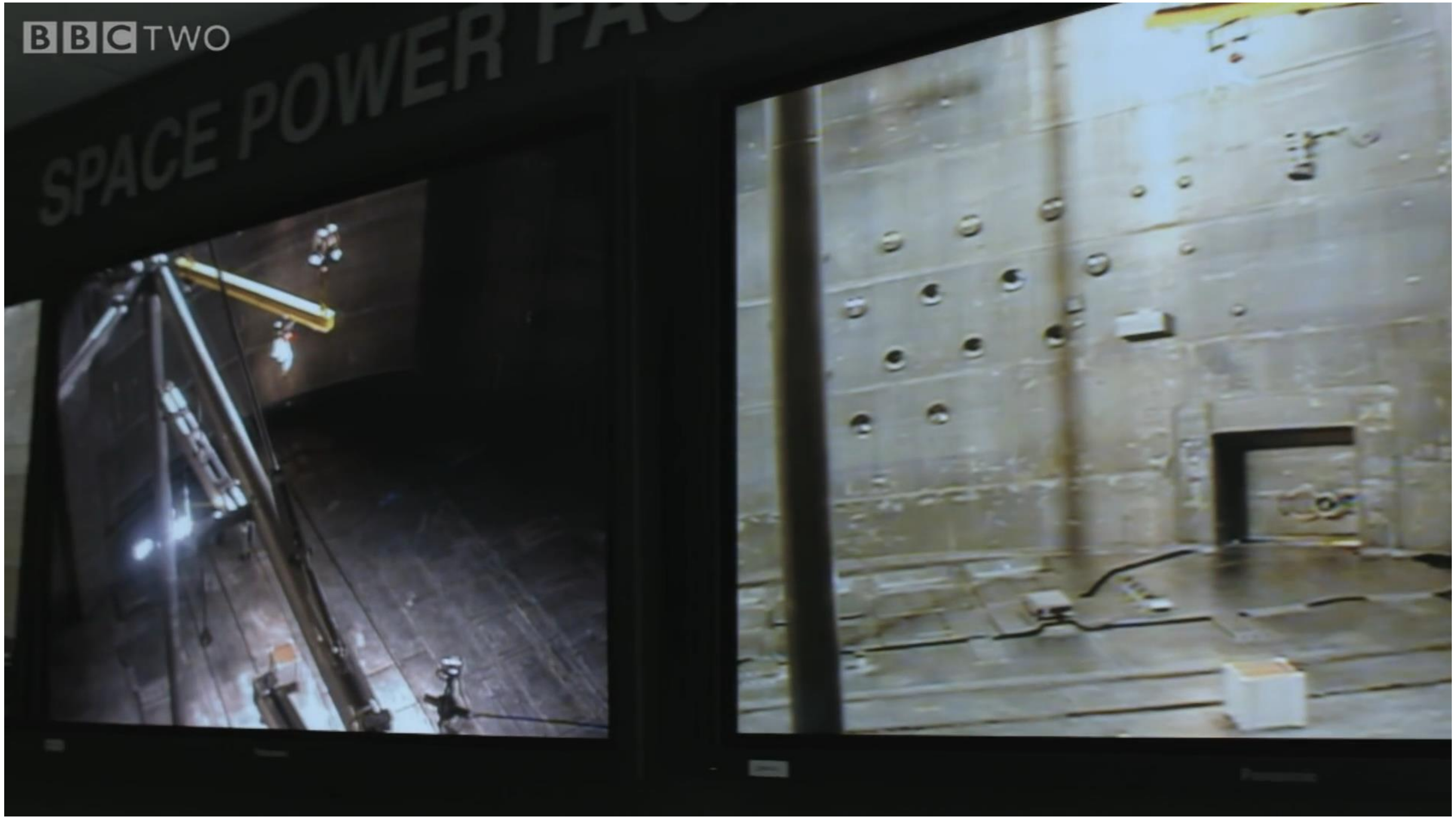
$$\vec{F}_{net,1} = \vec{W} = -m_1 g \hat{j}$$

$$\vec{F}_{net,1} = m_1 \vec{a}$$

$$\vec{a}_1 = \frac{\vec{F}_{net,1}}{m_1} = \frac{\vec{W}}{m_1} = -g\hat{j}$$

Similarly $\vec{a}_2 = -g\hat{j}$

Falling in vacuum



https://www.youtube.com/watch?v=E43-CfukEgs.

2. Newton's law of gravity

in general

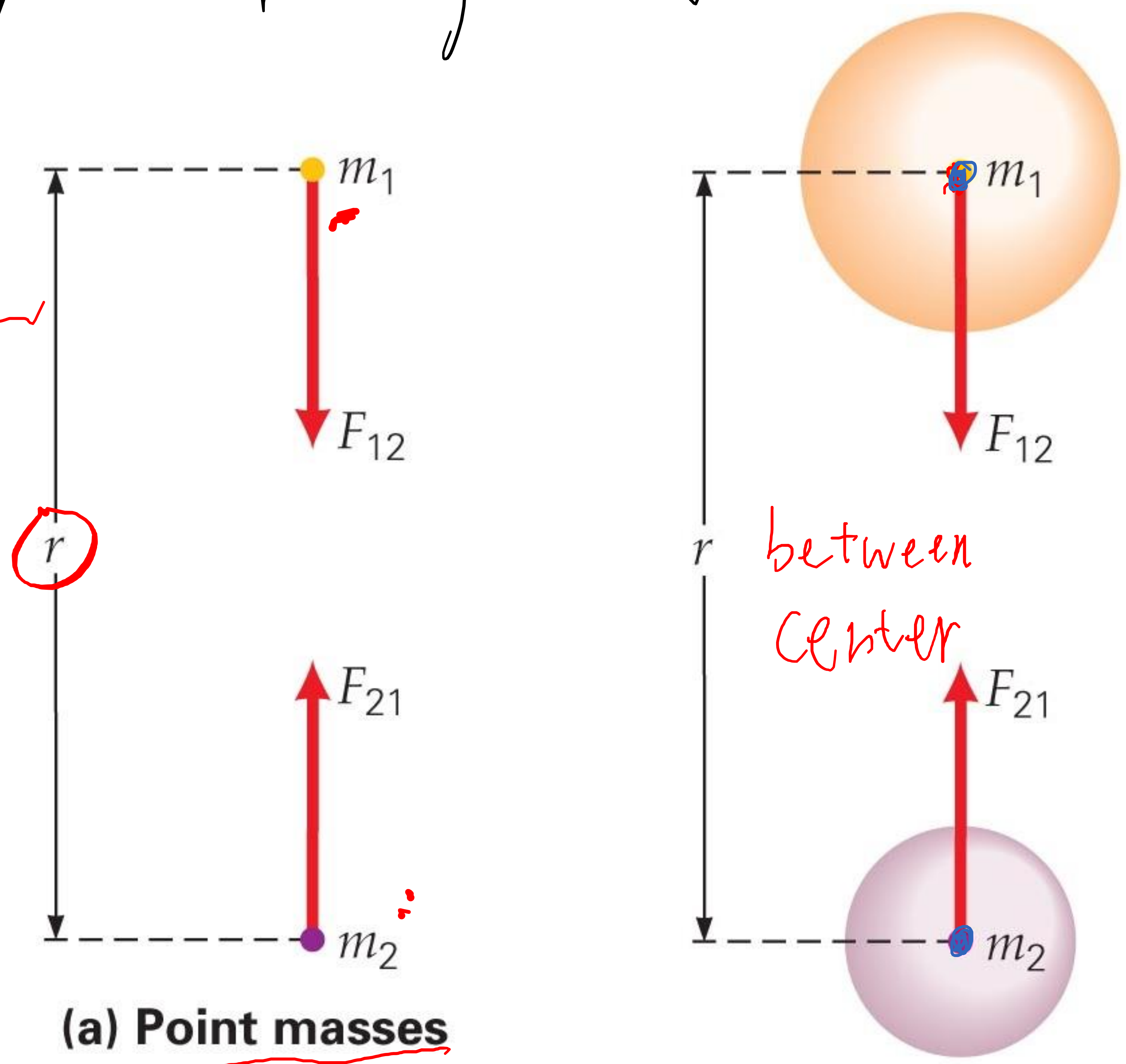
- **Gravity** = general attractive force between any two objects of the following magnitude and direction:

Gravitational constant, $G = 6.67 \times 10^{-11} \mathrm{N} \frac{\mathrm{m}^2}{\mathrm{kg}^2}$

Magnitude: $$|F_g| = \frac{G m_1 m_2}{r^2}$$

Distance between two objects

Direction: Pulling each of the two objects towards each other.

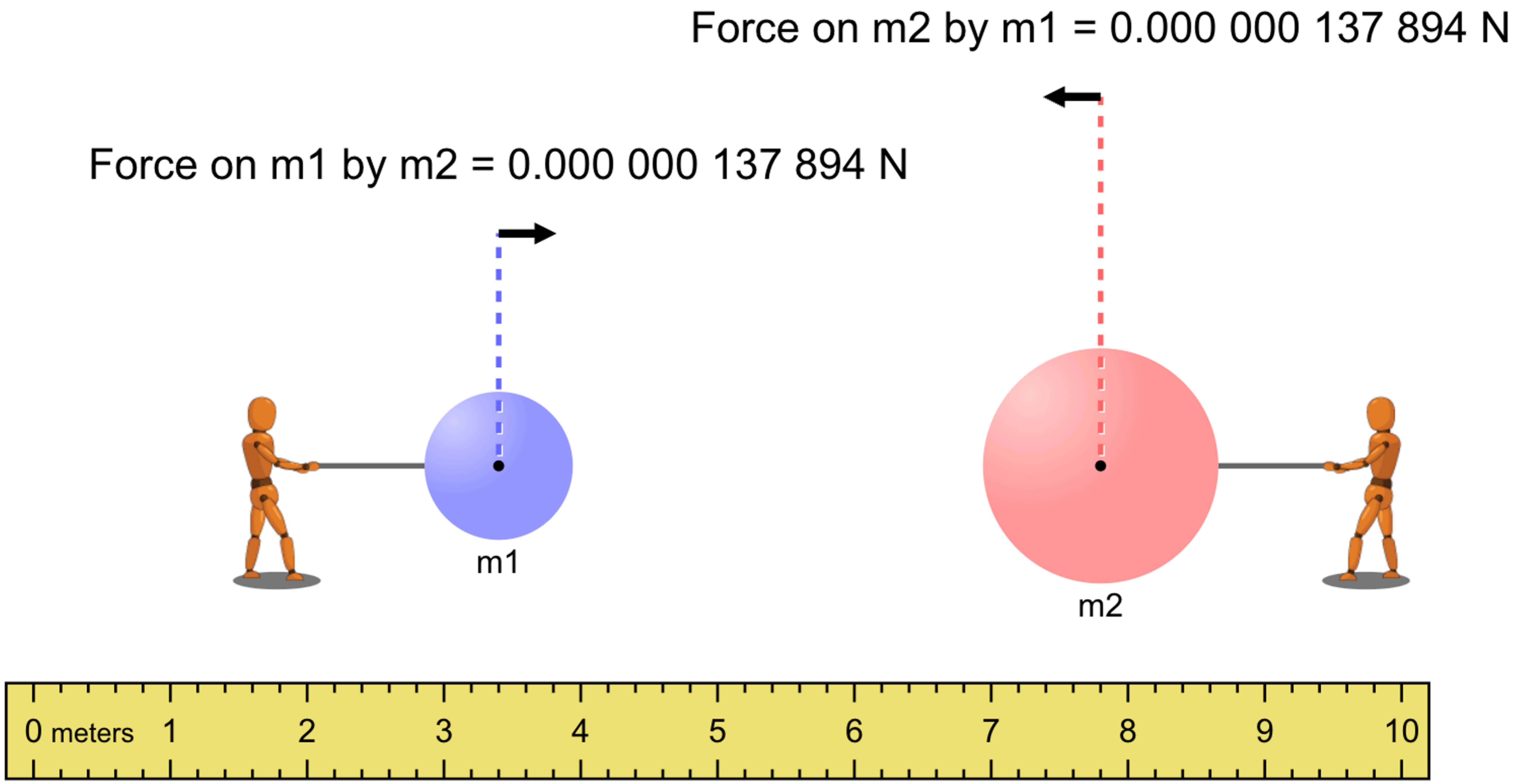


(a) Point masses

(b) Homogeneous spheres

$$\boxed{F_{12} = F_{21} = \frac{G m_1 m_2}{r^2}}$$

Simulation demo



https://phet.colorado.edu/sims/html/gravity-force-lab/latest/gravity-force-lab_all.html

Clicker question 2

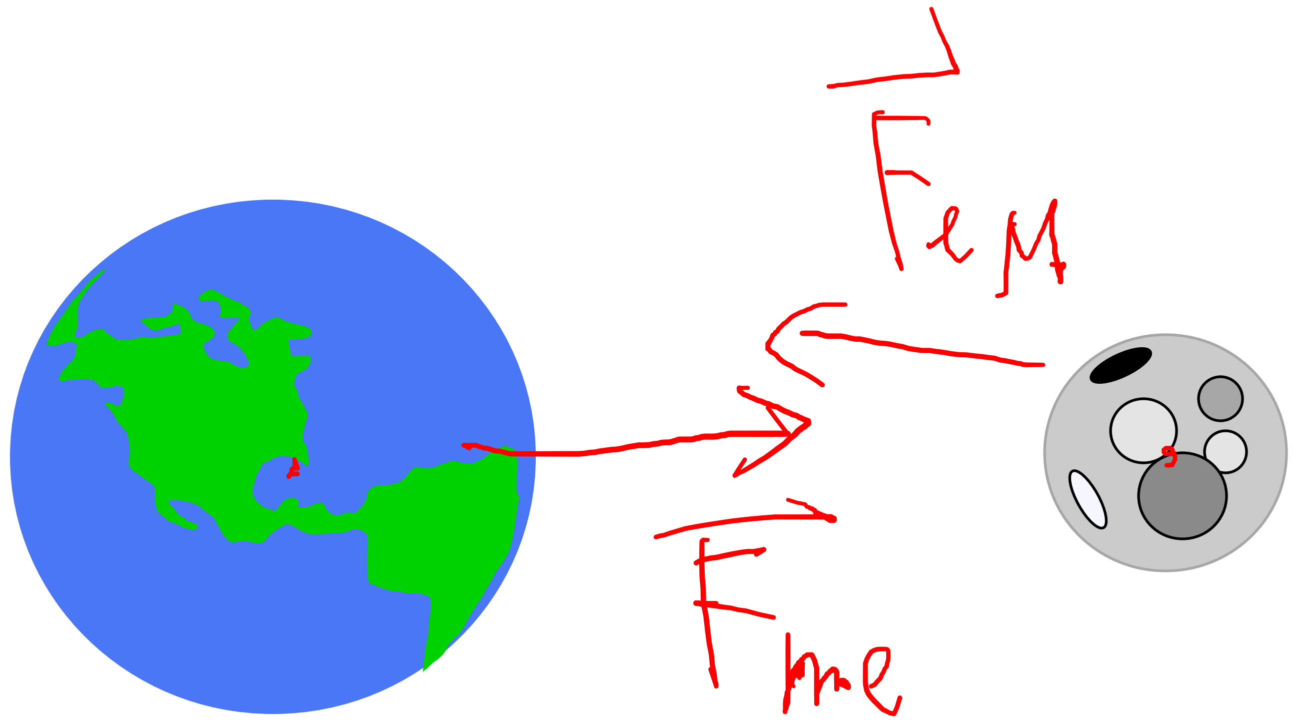
Question 7.7a **Earth and Moon I**

Which is stronger, Earth's pull on the Moon, or the Moon's pull on Earth?

A. the Earth pulls harder on the Moon
B. the Moon pulls harder on the Earth
C. they pull on each other equally
D. there is no force between the Earth and the Moon

$$|\vec{F}_g| = \frac{G m_E m_m}{r^2}$$

Distance

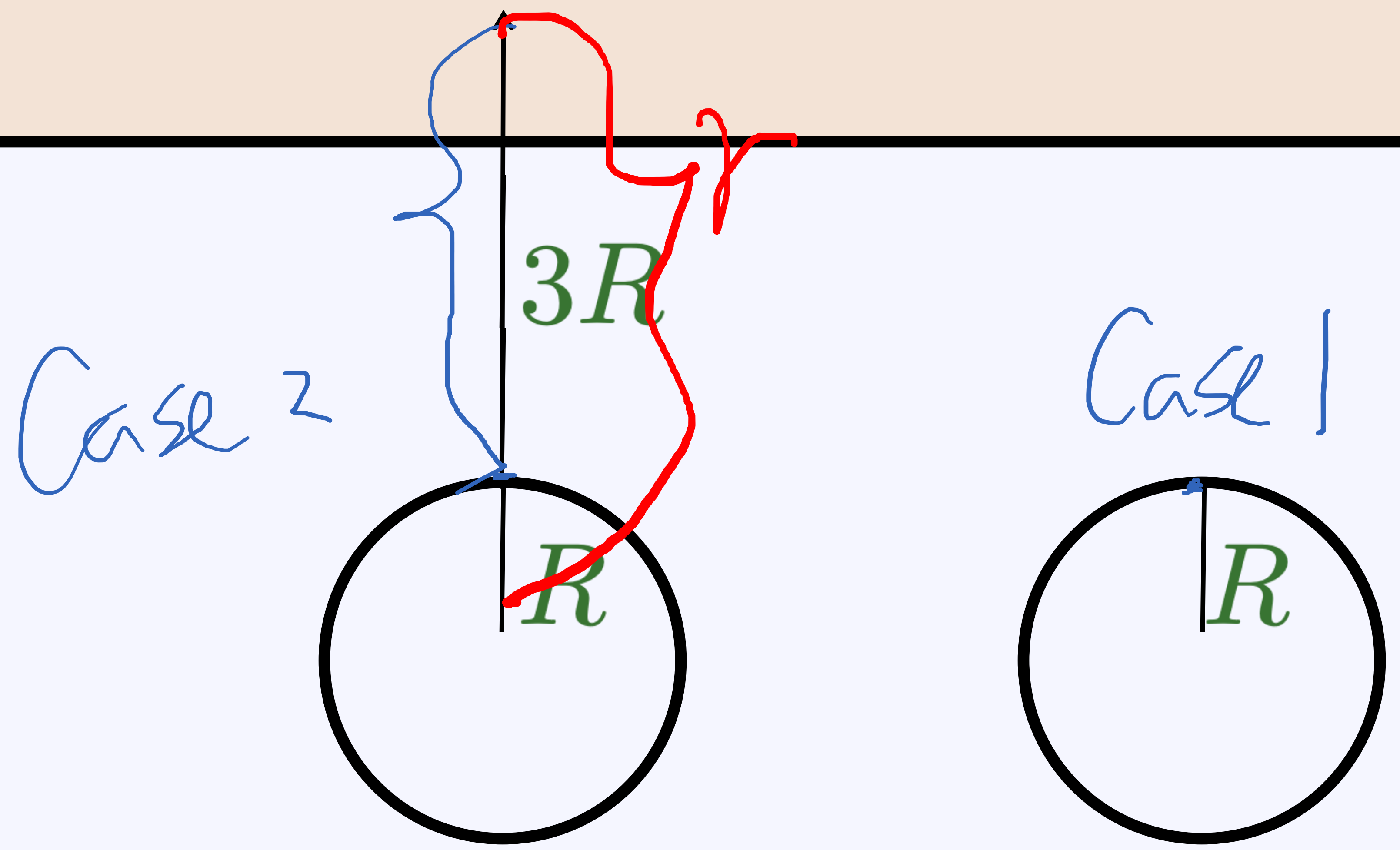


Clicker question 3

Earth and satellite

Compared to the force of gravity on an object on Earth's surface at the north pole, an object that is 3 * (earth radius) above the north pole of Earth, is

- A the same
- B 3 times smaller
- C 9 times smaller
- D 16 times smaller



$$|F_g| = \frac{G m_1 m_2}{r^2}$$

Distance

$$|F_{g_1}| = \frac{G m_1 m_2}{R^2}$$

$$|F_{g_2}| = \frac{G m_1 m_2}{(4R)^2}$$

Given: R_E, M_E, G

Example 1: Gravity on Earth

G

$g \rightarrow$ Grav. acc. const.

Goal: $|\vec{a}|$ due to grav. by Earth

- Earth radius is $R_E = 6371$ km, Earth mass is $M_E = 5.972 \times 10^{24}$ kg, Newton's constant of gravitation is $G = 6.674 \times 10^{-11}$ N m^2 kg^{-2}
- What is your acceleration due to gravitation by the Earth, right after you jumped at the Earth's surface? (Neglect air resistance.)

Assume: $\vec{F}_{net} = \vec{F}_g$;

Step 1: $\vec{F}_{net} = m\vec{a} \rightarrow \vec{a} = \frac{\vec{F}_{net}}{m}$

Step 2: Assumed: $|\vec{F}_{net}| = |\vec{F}_g| = \frac{G m M_E}{R_E^2}$

$N \sim kg \cdot m \cdot s^{-2}$

$|\vec{a}| = \frac{|\vec{F}_g|}{m} = \frac{G M_E}{R_E^2}$

Step 3:

$= \frac{6.674 \times 10^{-11} \, N m^2 kg^{-2} \times 5.972 \times 10^{24} kg}{(6371000 m)^2}$

$\approx 9.8 \, m s^{-2} \sim g$

Example 1: Gravity on Earth

- Earth radius is $R_E = 6371$ km, Earth mass is $M_E = 5.972 \times 10^{24}$ kg, Newton's constant of gravitation is $G = 6.674 \times 10^{-11}$ N m^2 kg^{-2}

- What is your acceleration due to gravitation by the Earth, right after you jumped at the Earth's surface?

$$F_{\text{net}} = F_{\text{grav}} = \frac{GM_E m_{\text{you}}}{R_E^2} = m_{\text{you}} a$$

$$a = \frac{GM_E}{R_E^2}$$

$a \approx (6.674 \times 10^{-11}$ N m^2 kg$^{-2})(5.972 \times 10^{24}$ kg$)/(6.371 \times 10^6$ m$)^2$

$a \approx 9.8$ N kg$^{-1} = 9.8$ m/s^2

Gravity and weight

In general, $|F_g| = \dfrac{G m_1 m_2}{r^2}$

Distance

$+y$

- **Weight**: Gravity on earth surface

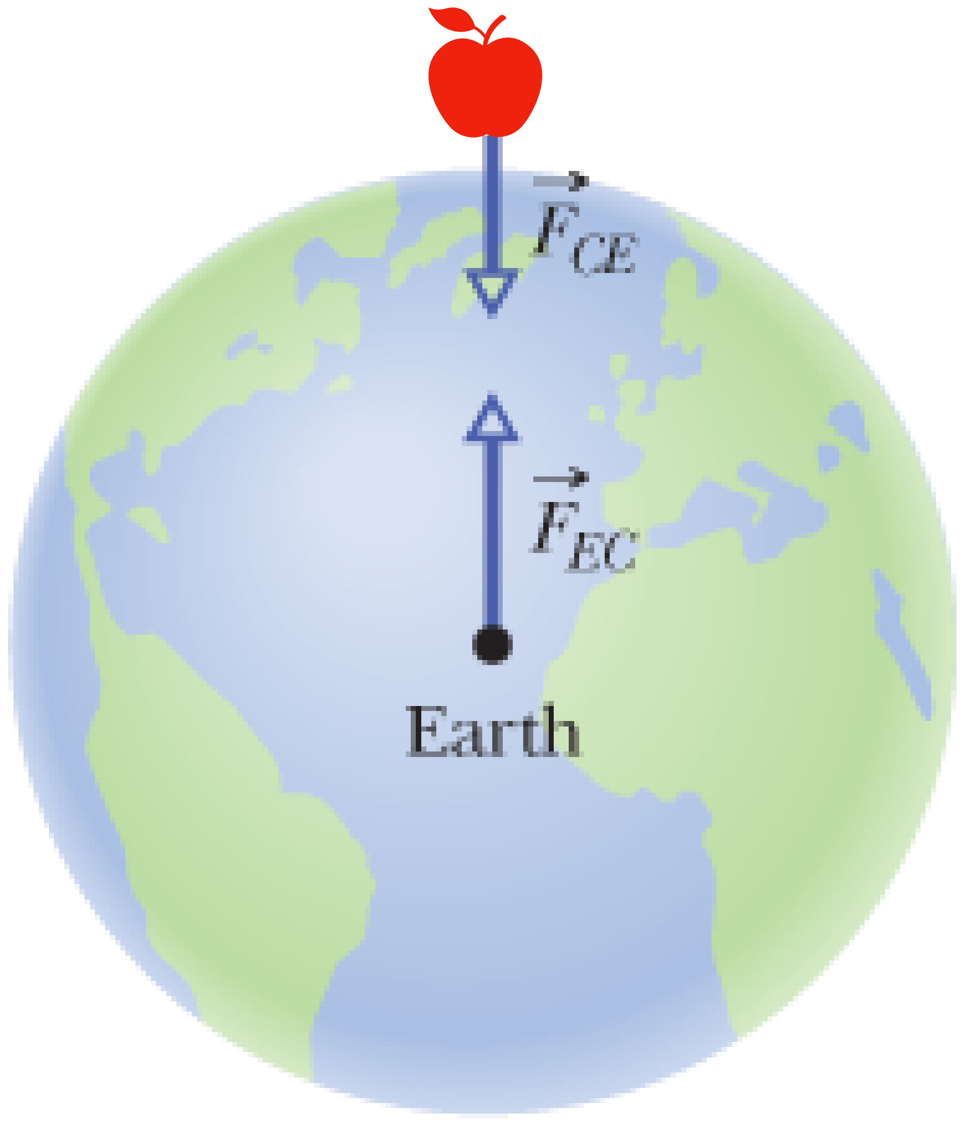
Grav. const.

$$|F| = \frac{G m M_E}{R_E^2}$$

$M_E = 6.0 \times 10^{24}$ kg

radius of earth

$R_E = 6.4 \times 10^{6}$ m



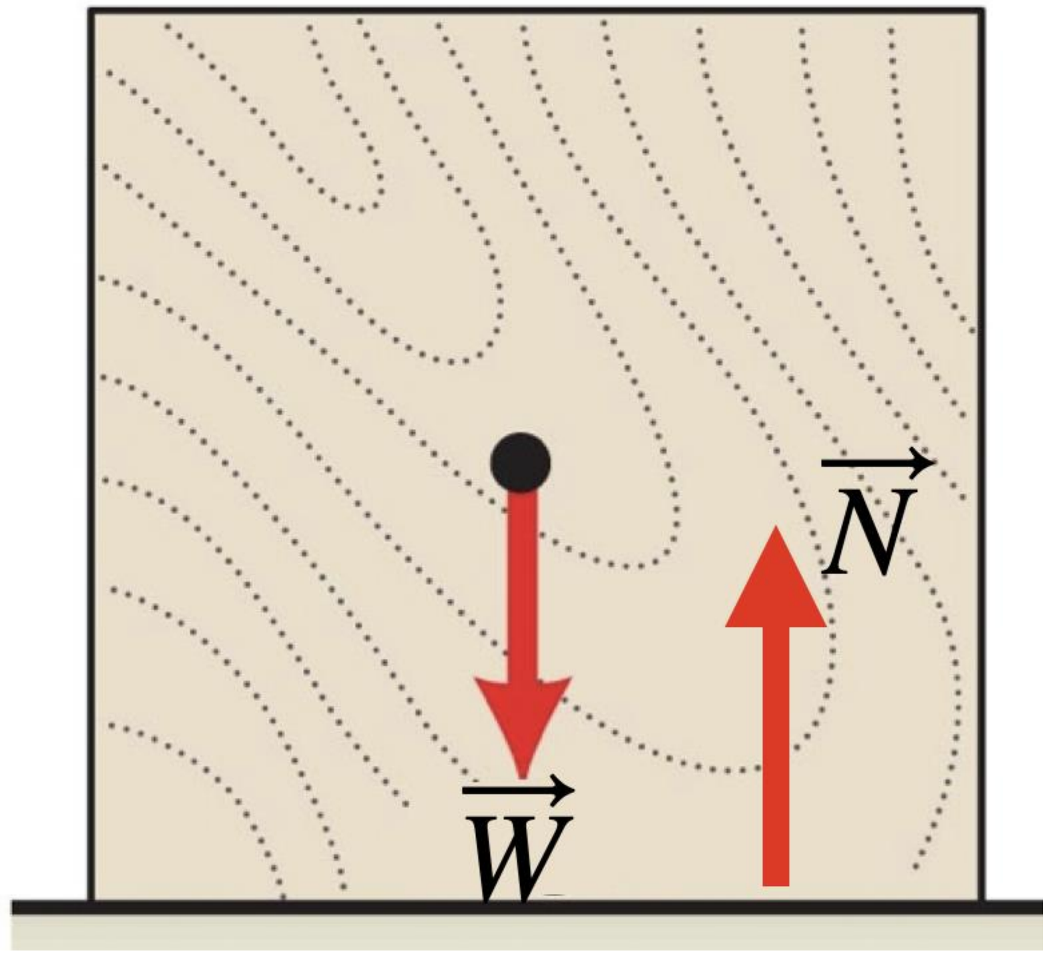
$$g = \frac{G M_E}{R_E^2} \approx 9.8 m/s^2$$

Grav. acc. const. on earth surf.

Therefore, $\vec{W} = -mg\hat{j}$

3. Normal force

- Normal force: The support force when two objects are in contact
  - Direction: perpendicular to surface
  - Magnitude: exactly enough so object remains on surface



Clicker question 4

$\uparrow y$

$\vec{F}_{net} = m\vec{a} = 0$, $\vec{a} = 0$

$\vec{W} + \vec{N}_{bt} = 0 \rightarrow \vec{N}_{bt} = -\vec{W} = -(-mg\hat{j}) = mg\hat{j}$

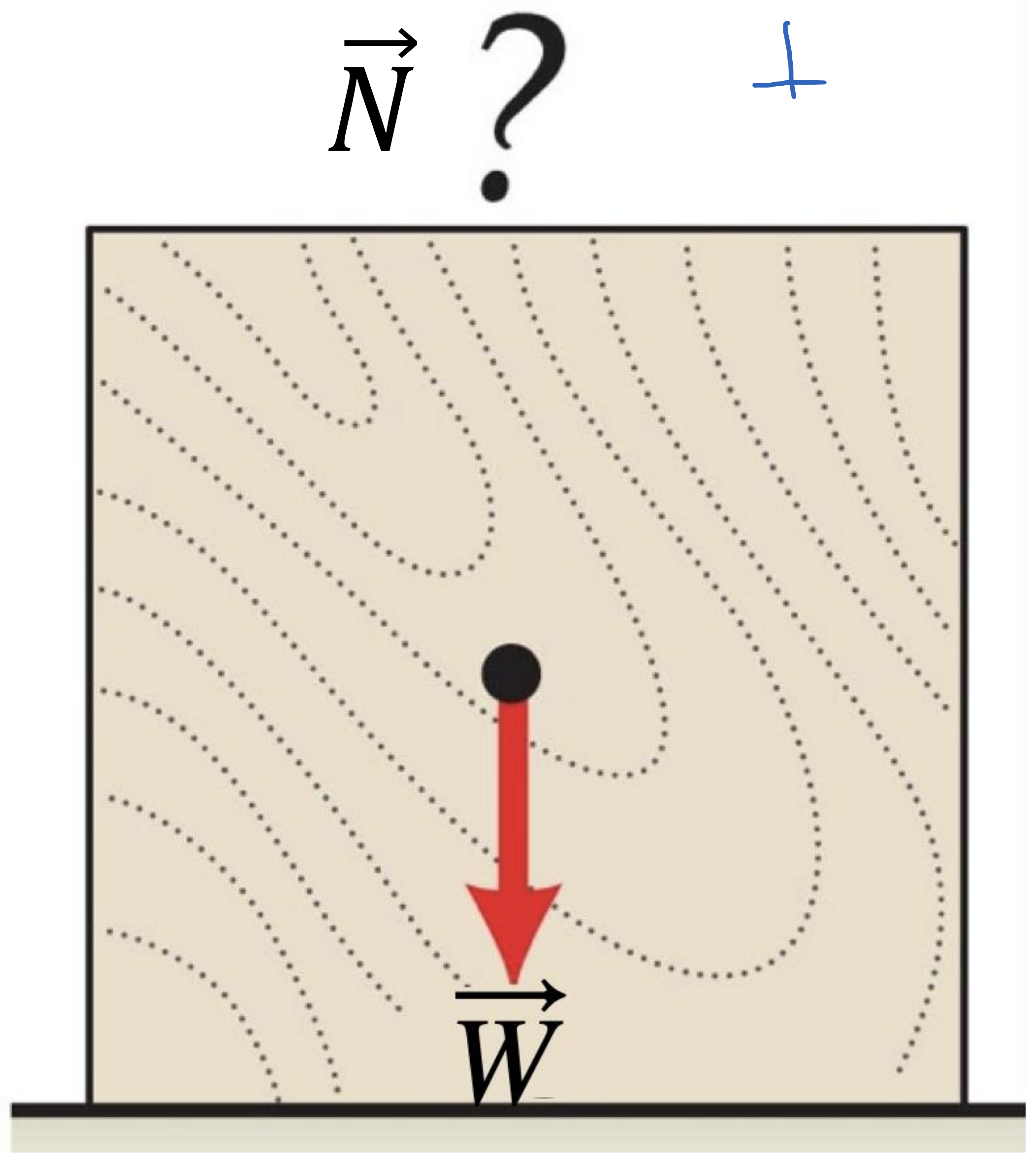
- A box of weight $\vec{W}$ is placed at rest on a horizontal surface of a table. $\vec{N}_{bt}$ is the normal force on the box by the table, and $\vec{N}_{tb}$ is the normal force on the table by the box. Which of the following is true?

A $\vec{N}_{bt}$ points down, $\vec{N}_{tb}$ points up

B $\vec{N}_{bt}$ points up, $\vec{N}_{tb}$ points down

~~C~~ $\vec{N}_{bt}$ points to the left, $\vec{N}_{tb}$ points to the right

~~D~~ $\vec{N}_{bt}$ points to the right, $\vec{N}_{tb}$ points to the left

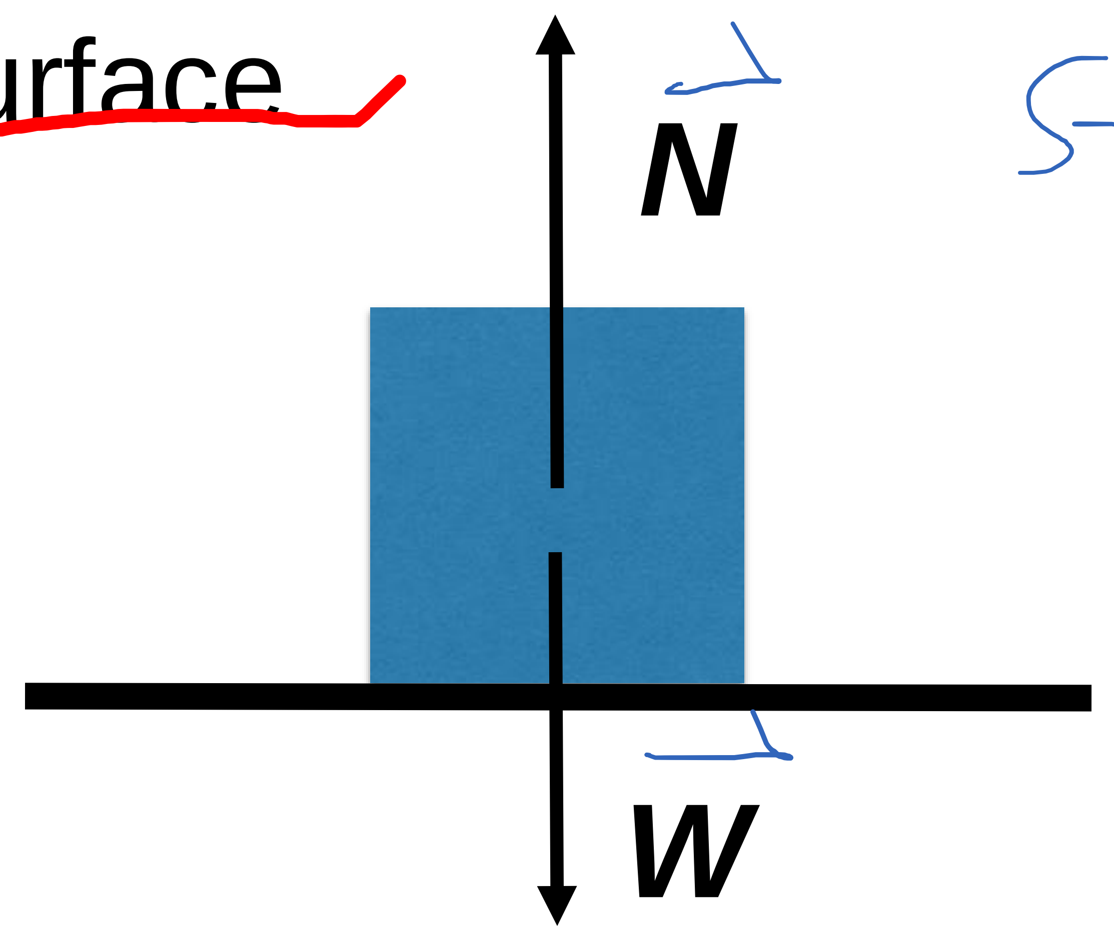


A helpful tool: Free Body Diagrams (FBD)

- FBDs are a graphical illustration of applied forces
- Each force is drawn as a vector indicating direction
- If a force is not along x, y or z directions, then the force components are drawn, too
- **Free body diagrams** will be very useful for solving **force & motion** problems

Step1: Axis

Example: A block is at rest on a surface



Step2: Draw forces

Step 3: Decomp-ose along x-or y-

Steps to draw a Free Body Diagram (FBD)

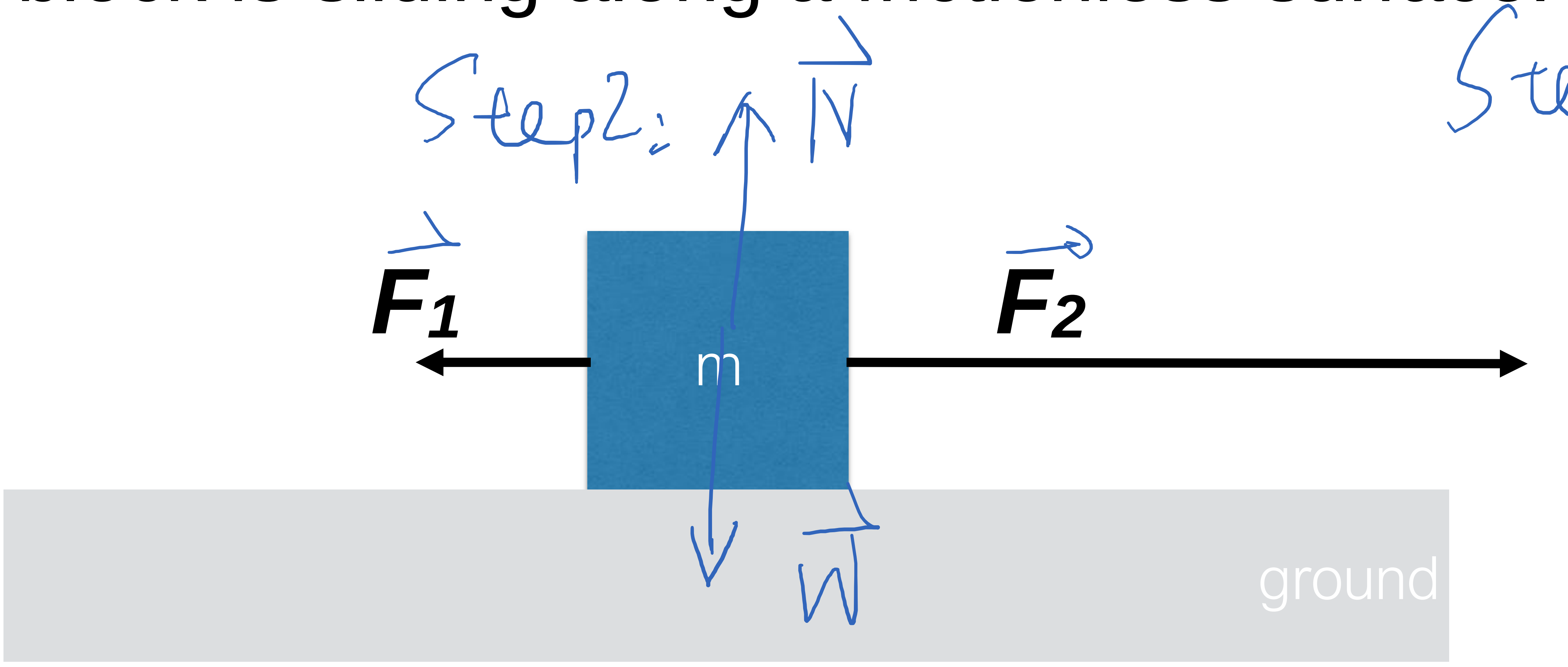
- **Step 1:** Draw the coordinate system Axes
- **Step 2:** Draw the forces on the object or system
- **Step 3:** Decompose the forces that are not along the coordinate axes

Example 1: Free Body Diagrams

Step1:

A block is sliding along a frictionless surface.

Step 3:



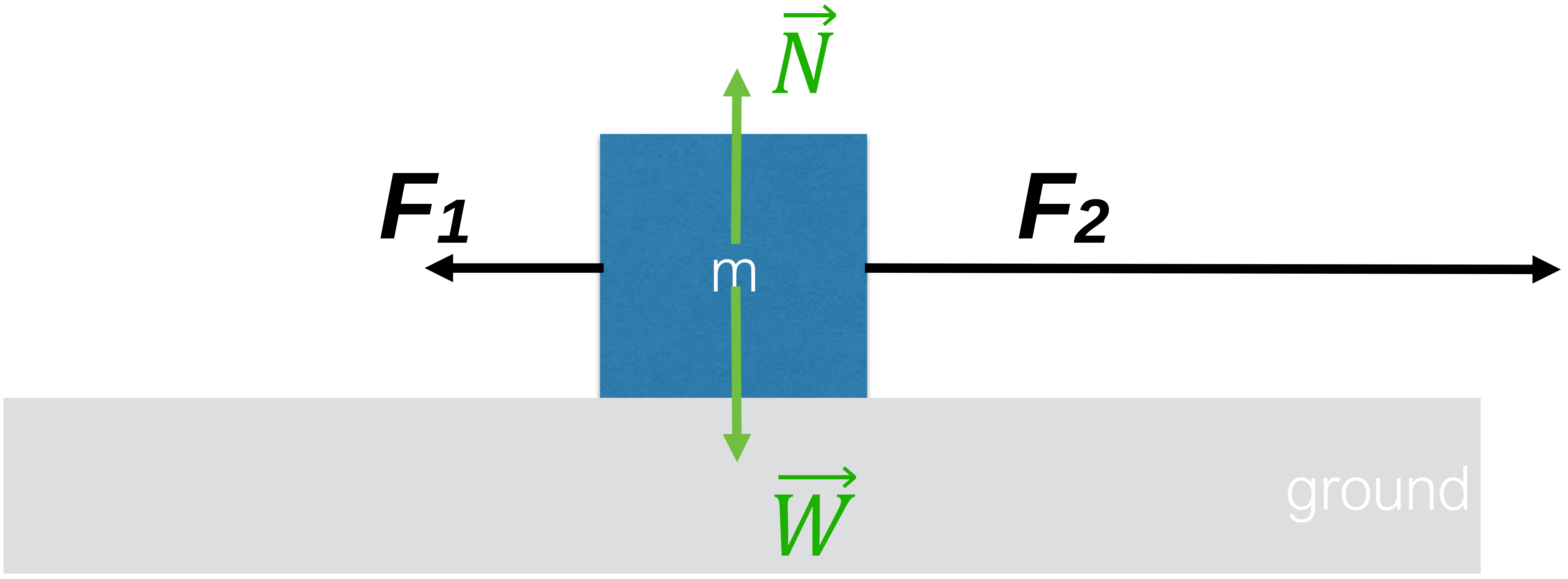
$m = 1$ kg
$F_1 = 2$ N
$F_2 = 8$ N

- How to draw the free body diagram?
  - The x-direction is basically done…
  - What about the y-direction?

Example 1: Force & motion

FBD, 2nd

A block is sliding along a frictionless surface. What is its acceleration? What is the normal force?



Given:

$m = 1$ kg

$|F_1| = 2$ N

$|F_2| = 8$ N

Goal: $\vec{a}$, $\vec{N}$

Step 1: $\vec{a}_y = 0$

2nd law: $\vec{F}_{net,y} = 0 = \vec{W} + \vec{N}$

Rewrite: $\vec{N} = -\vec{W} = -(-mg\hat{j})$

$= mg\hat{j}$

$= 1\,kg \times 9.8\,ms^{-2}\hat{j}$

$= 9.8\,N\hat{j}$

Step 2: $\vec{a} = \vec{a}_x$

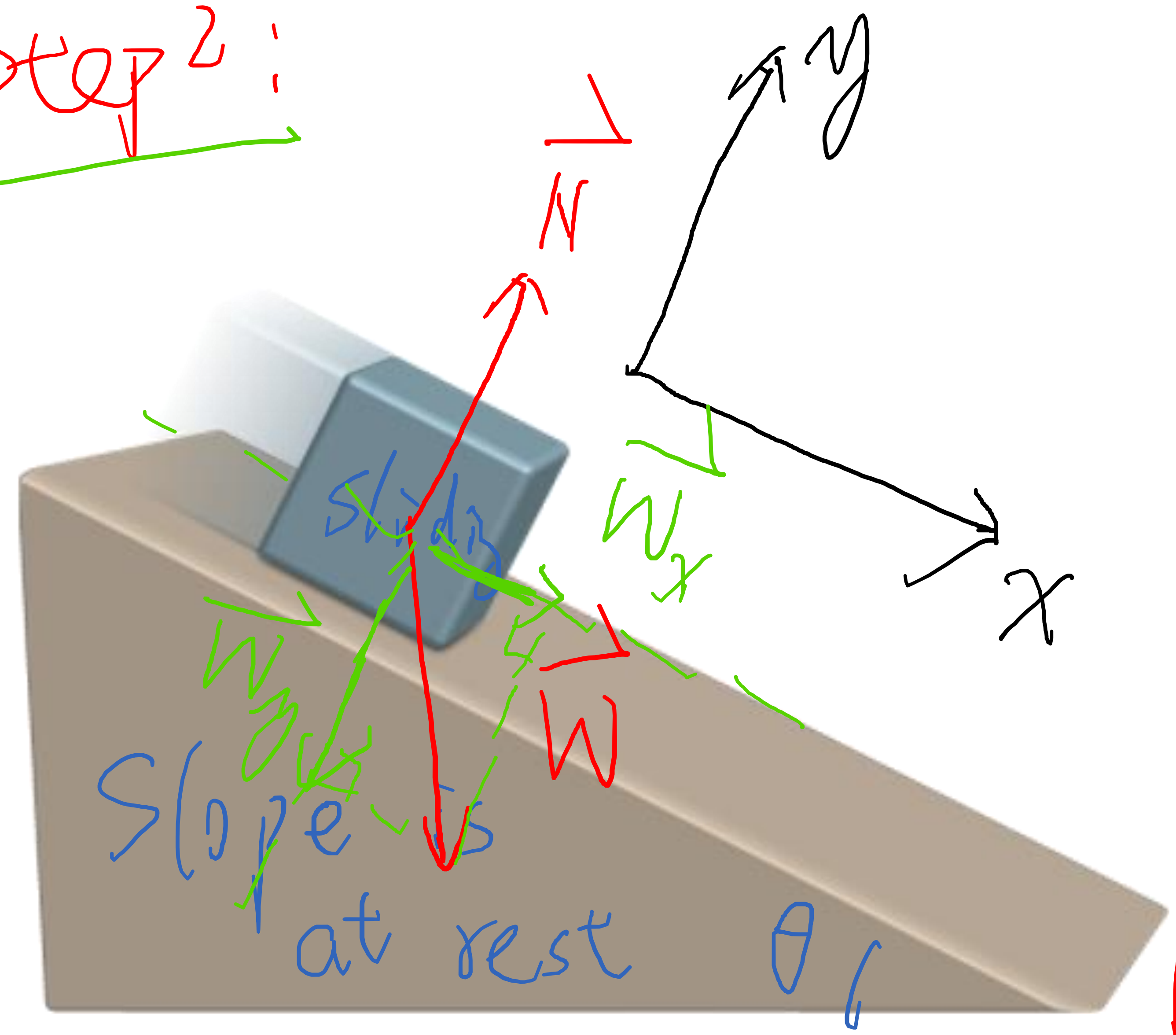
2nd law in x dir. $\vec{F}_{net,x} = m\vec{a}_x$

$\rightarrow \vec{a}_x = \dfrac{\vec{F}_{net,x}}{m} = \dfrac{8N\hat{i} - 2N\hat{i}}{1\,kg} = 6\,ms^{-2}\hat{i}$

FBD Examples on inclines

Step 1:

Step 2:



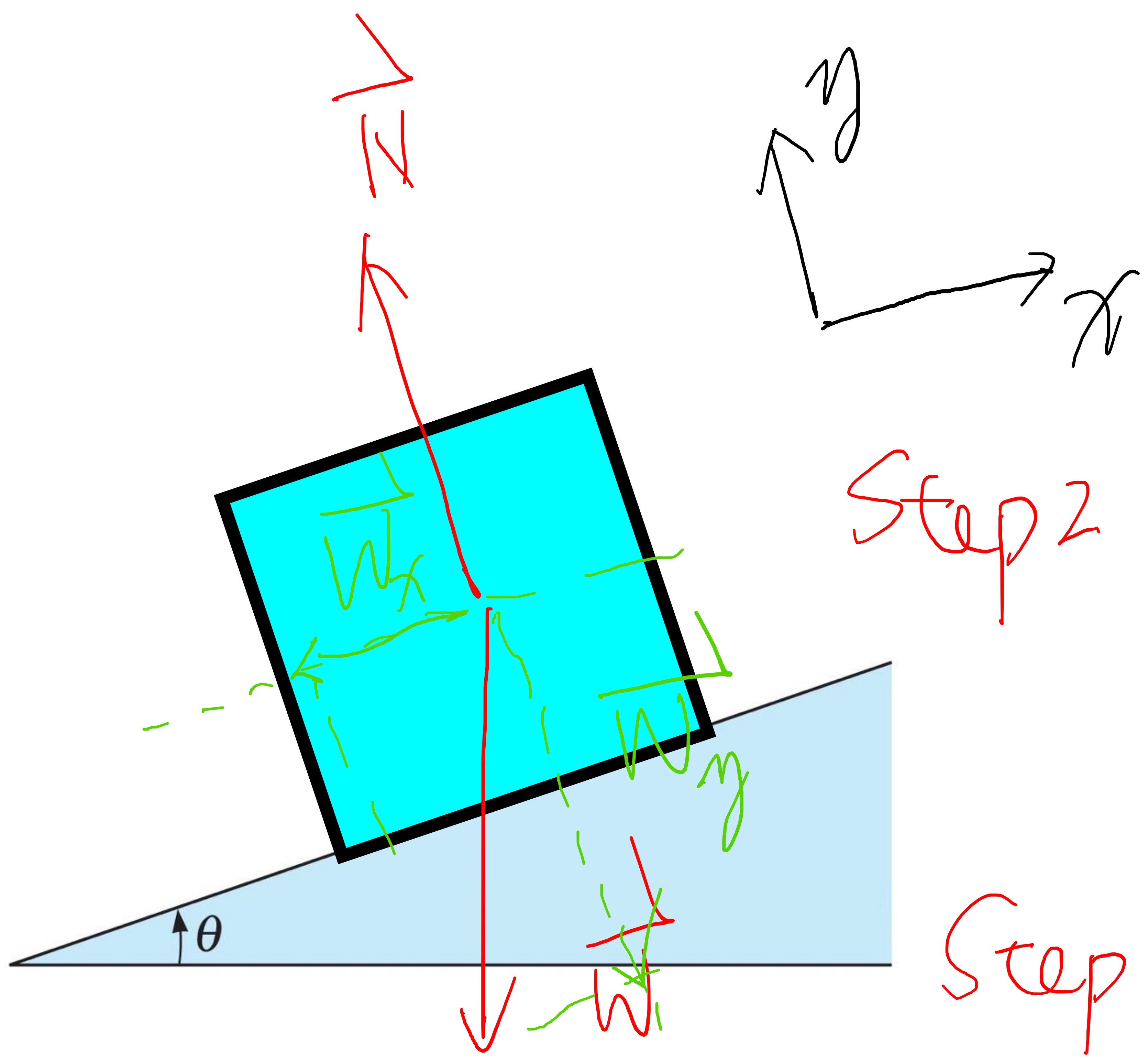
$\vec{a}_y = 0$

Frictionless

No air resistance

Step 3: Decompose

Step 1:



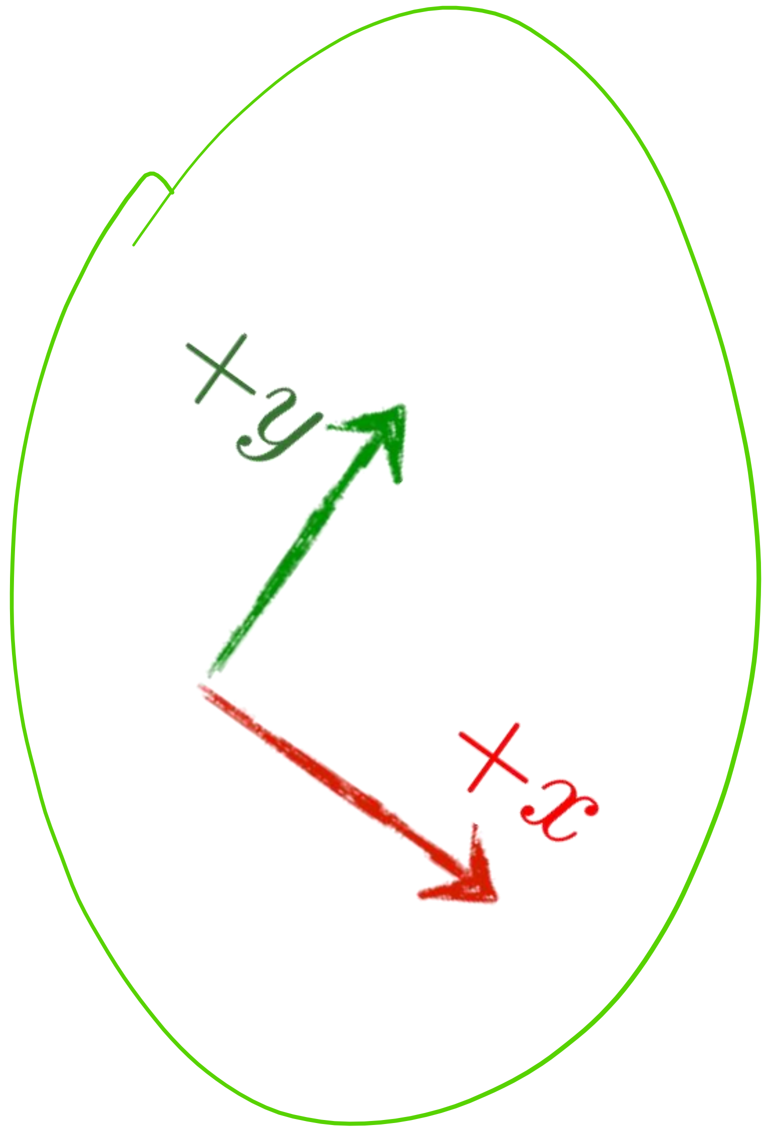
Step 3.

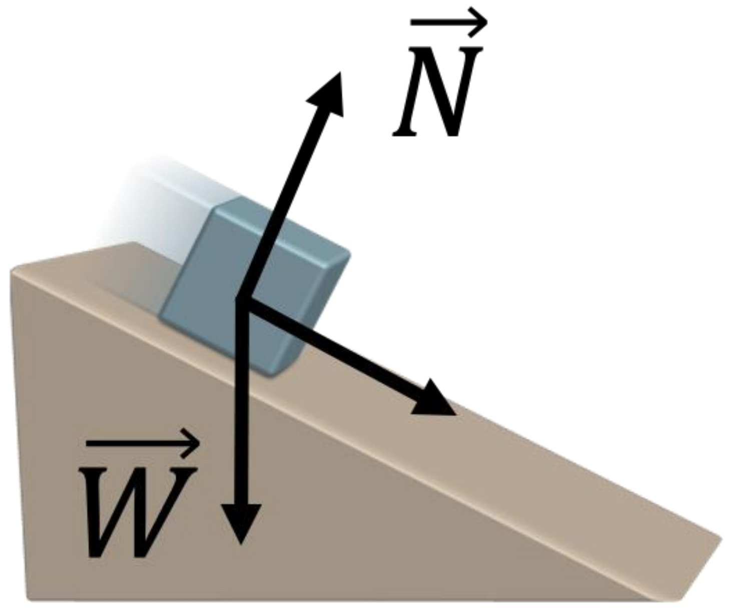
Clicker Question 5

A block slides down a frictionless inclined plane. Which of the following correctly sketches the free body diagram for all forces acting on the block?

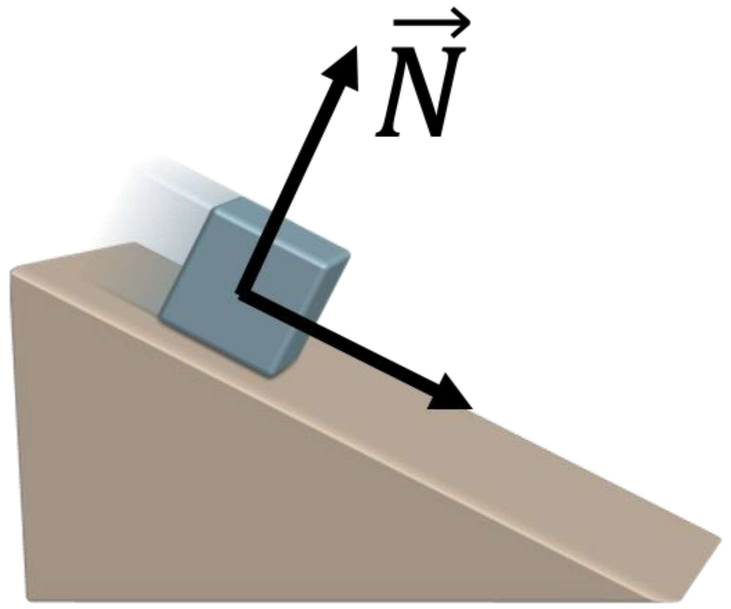
Step 1

Axes

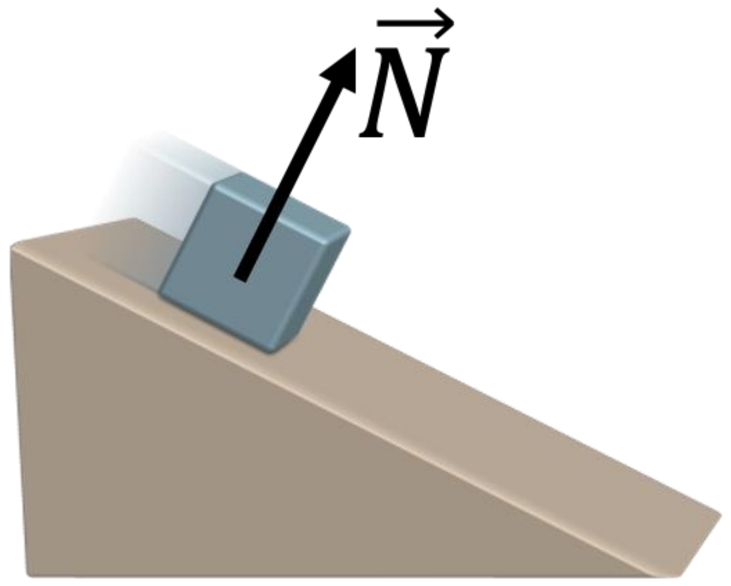




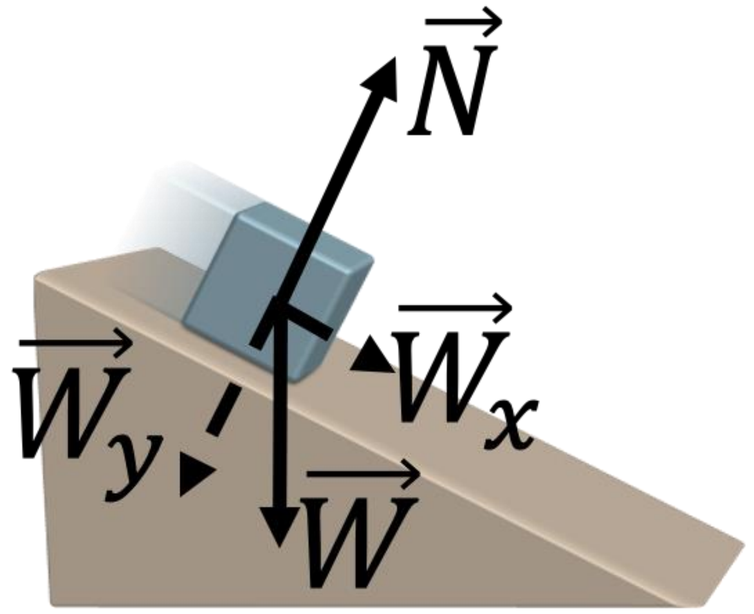
A



B



C



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Step 2.

Step 3

Chapters before Midterm 1:

Oct. 17

- **Chapter 1:** Unit conversion: chain-link rule
- **Chapter 2:** 1D motion: Scalar vs. vector, average vs. instantaneous displacement, velocity and acceleration, 4 kinematics equations, stopping distance
- **Chapter 3:** Vectors: Vector decomposition, vector addition, multiplication
- **Chapter 4:** Projectile motion; Uniform circular motion, reference frames
- **Chapter 5 (part):** Force and motion: Newton's three laws, specific forces, free body diagram
- **Study guide:** Canvas Exam module (practice, review, study guide), pre-lecture surveys, in-class examples, clicker questions, homework
- **Midterm1:**
  - Closed book, closed notes, however, you can bring ~~a 1-page 1-sided cheat sheet~~
  - Calculators are allowed
  - Academic integrity is important. Academic dishonesty will lead to a zero to the midterm.