Hi!

# Chapter 5 – Forces

- What are forces (in physics)
- Concept: System
- New representation: Free-Body Diagrams (FBD)
- Newton’s Laws



- Substitute Professor today:
- **Jason Harlow** (also the PHY151 Practicals Coordinator!)
- Professor Wilson is in an important workshop right now that he could not get out of; he will be back on Monday.

From the course Quercus page

Outside Links of Interest (not directly course related)

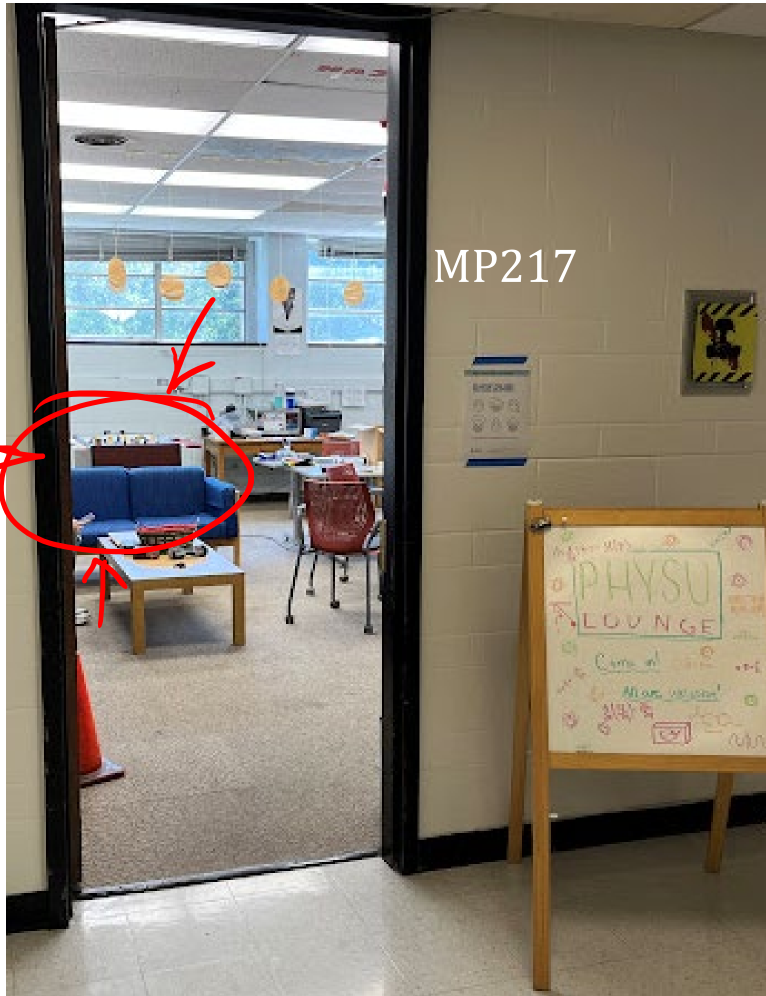
PhySU

Physics Student Union

UNIVERSITY OF TORONTO

- **PhySU the Physics Student Union** represents all students who are enrolled in a physics subject POSt or who are taking a physics course (that's *you!*)
- https://www.facebook.com/groups/pasu.physics
- https://www.instagram.com/physu/
- https://www.physu.org
- First Year Representative applications are open today, and will close in 2 weeks.
- Also in real life in MP217.
- They say: *"Feel free to stop by anytime! We have a microwave, free printing, free sanitary products, office supplies, and a cheap snack bar!"*

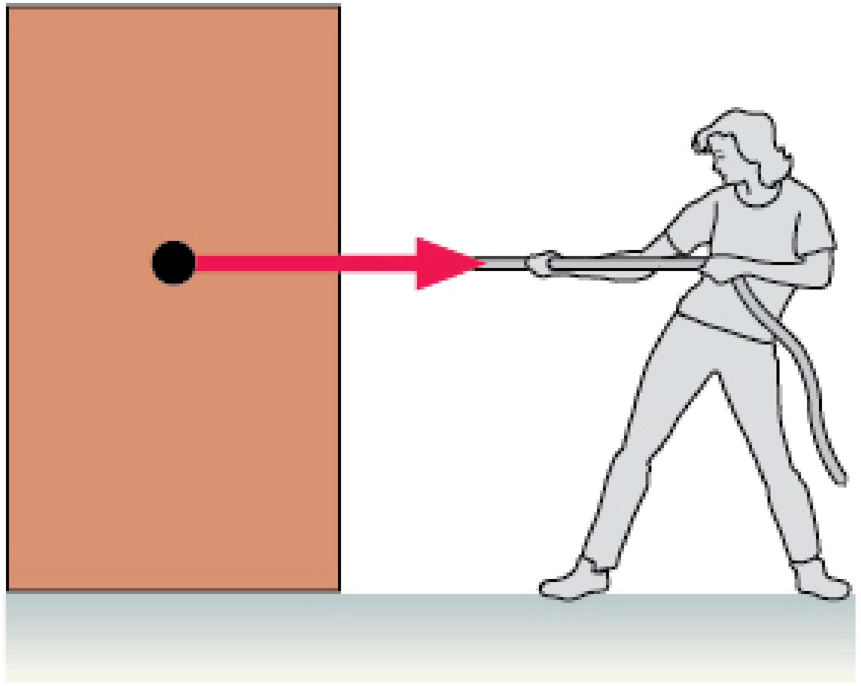
foozball table!



# What is a force?

The fundamental concept of **mechanics** is **force**.

- A force is a **push** or a **pull**.
- A force acts on an object.
- A force requires an **agent**.
- A force is a **vector**.



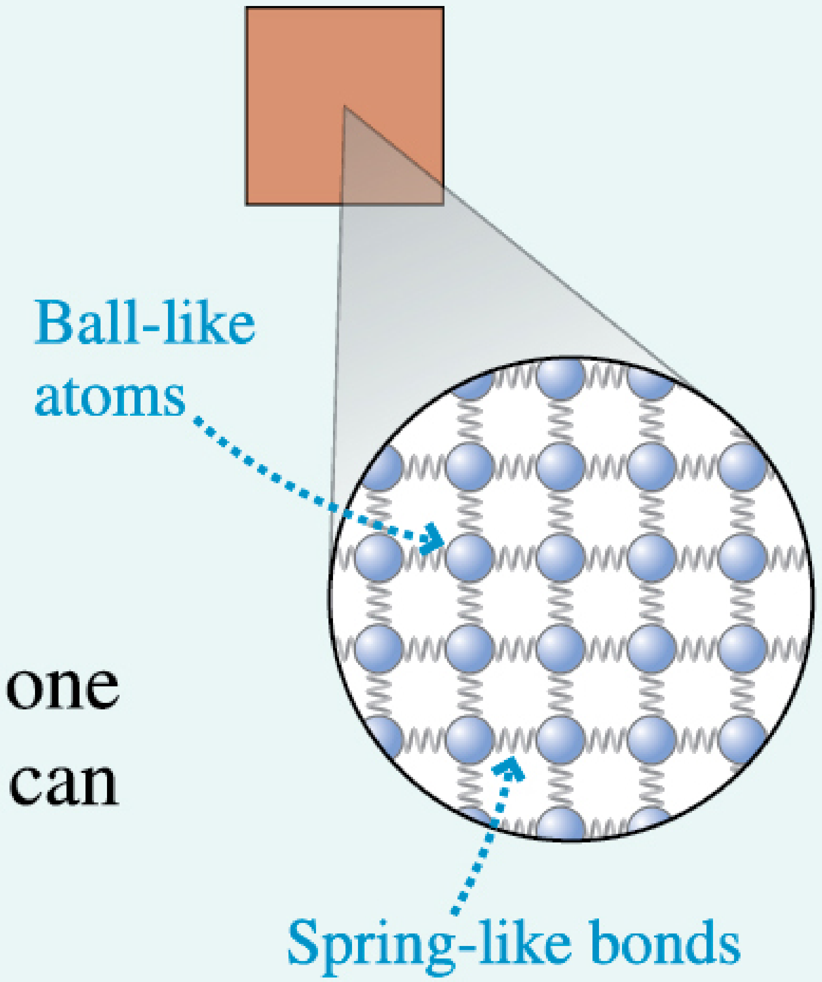
- Quantum mechanics does not have forces.
- Forces are macroscopic sums of trillions of momentum transfers between particles.
- Forces are a huge simplification of what's really happening at the microscopic level!

## MODEL 5.1

### Ball-and-spring model of solids

Solids consist of atoms held together by molecular bonds.

- Represent the solid as **an array of balls connected by springs.**
- Pulling on or pushing on a solid causes the bonds to be stretched or compressed. **Stretched or compressed bonds exert spring forces.**
- There are an immense number of bonds. The force of one bond is very tiny, but the combined force of all bonds can be very large.
- Limitations: Model fails for liquids and gases.



| Force | Notation |
|---|---|
| General force | $\vec{F}$ ← as specified |
| Gravitational force | $\vec{F}_G = mg$, down, where $g = 9.8\ N/kg$ |
| Spring force | $\vec{F}_{Sp} \simeq k(\Delta x)$, restoring force. |
| Tension | $\vec{T}$ ← as needed |
| Normal force | $\vec{n}$ ← as needed |
| Static friction | $\vec{f}_s$ ← as needed |
| Kinetic friction | $\vec{f}_k \simeq \mu_k n$, slows down sliding |
| Drag | $\vec{F}_{drag} \simeq \frac{1}{2} C \rho A v^2$, slows down things Eq. 6.15 |
| Thrust | $\vec{F}_{thrust}$ ← as specified |

Could be zero, if not need

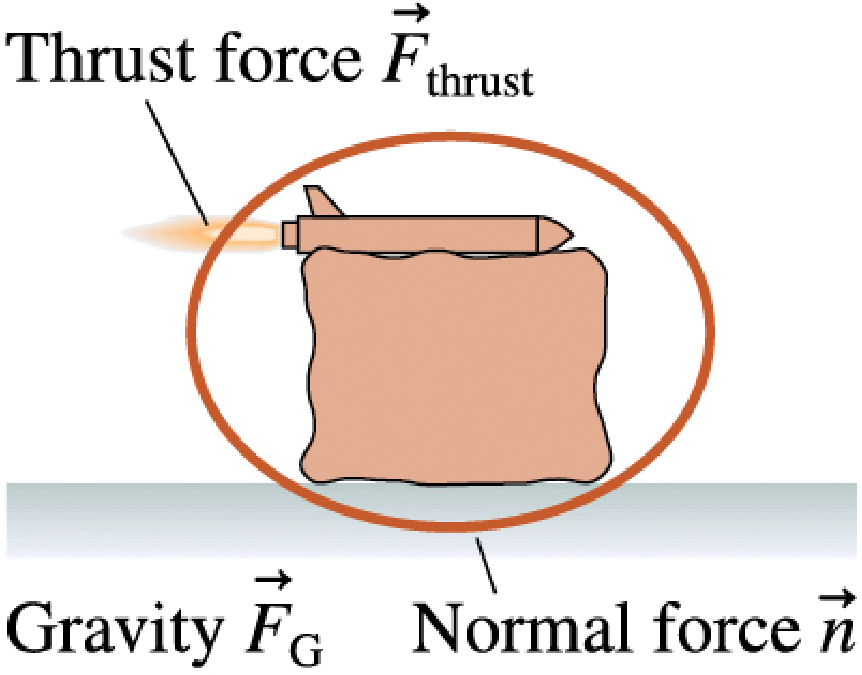
← all have maximum magnitude

# Summary

## Key Skills

### Identifying Forces

Forces are identified by locating the points where other objects touch the object of interest. These are points where contact forces are exerted. In addition, objects with mass feel a long-range gravitational force.

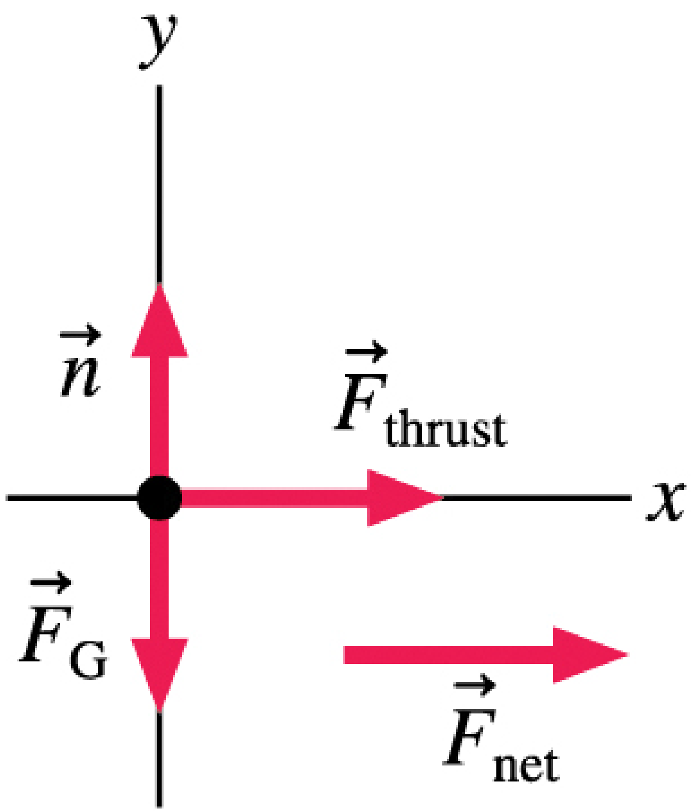


# Summary

## Key Skills

### Free-Body Diagrams

A free-body diagram represents the object as a particle at the origin of a coordinate system. Force vectors are drawn with their tails on the particle. The net force vector is drawn beside the diagram.



# Team Up Question 1

Notation indices 1, 2

$F_{12}$ = force of 1 on 2

Three books are stacked on top of each other.

They are at rest and nothing else is touching them (other than the table below them!).

How many forces act on the middle book? Ignore air.

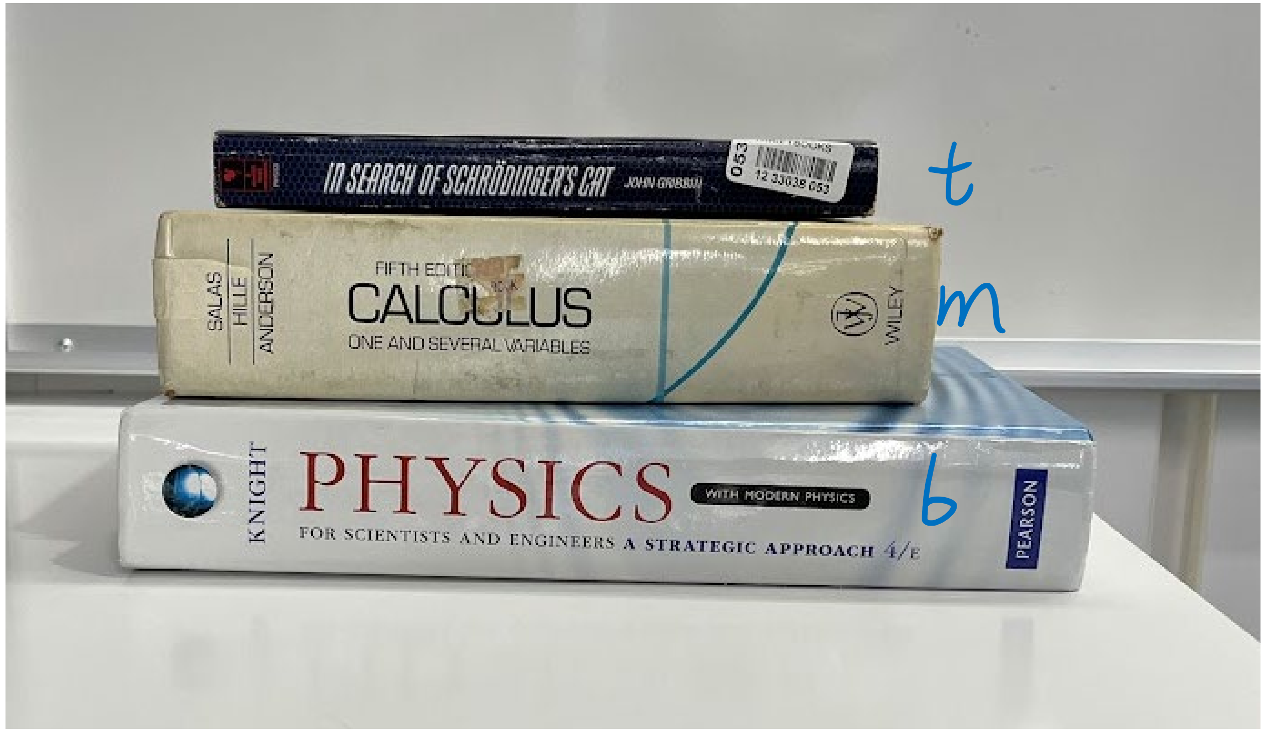
A. 1

B. 2

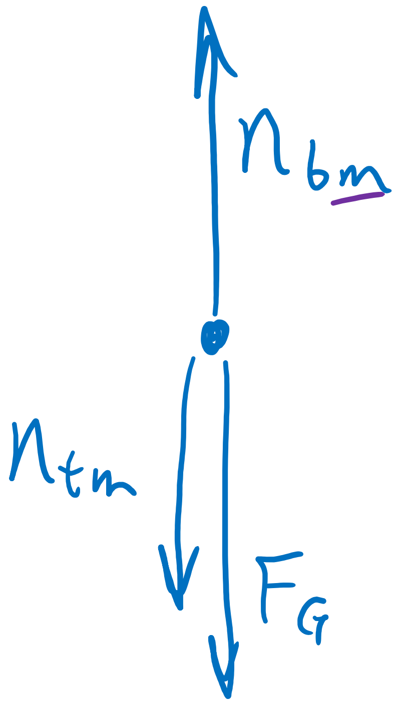
C. 3

D. 4

E. 5




Free body diagram of middle book



# Team Up Question 2

Please assume all 3 books have the same mass.

Three books are stacked on top of each other.

They are at rest and nothing else is touching them (other than the table below them!).

Which force acting on the middle book is largest?

A. The force of the top book on the middle book.

B. The force of the bottom book on the middle book.

C. The force of the table on the middle book.

D. The force of the Earth (gravity) on the middle book.

E. The two largest forces are equal in magnitude.

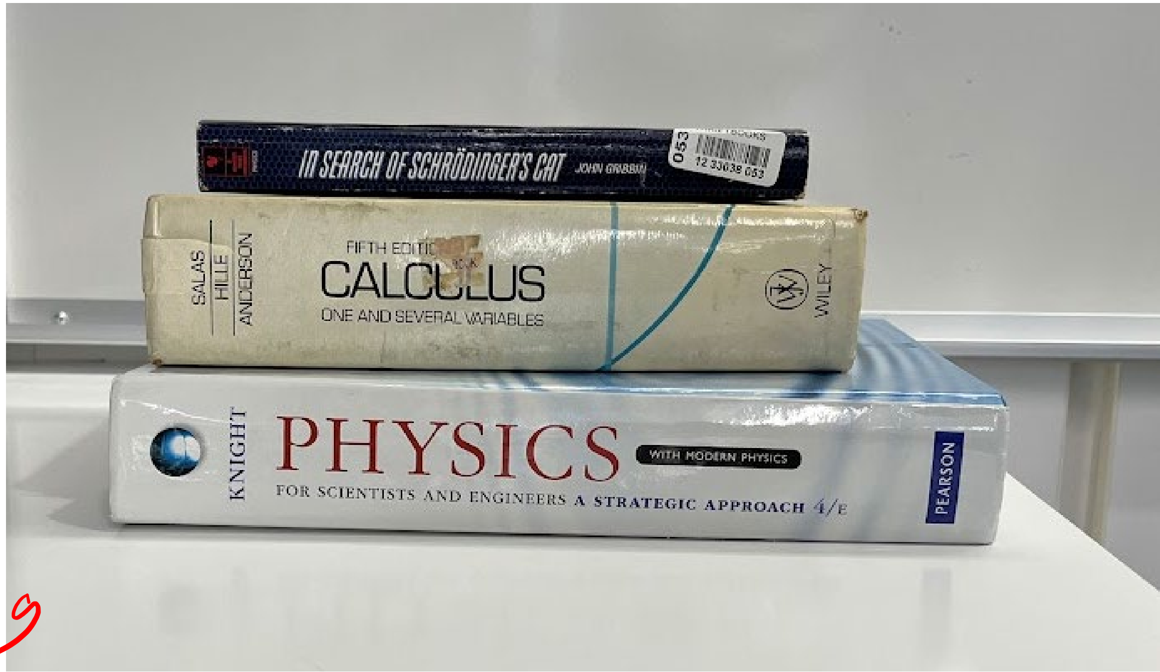
F. The force of the air on the middle book.

$n_{bm}$

$n_{tm}$ $F_G = mg$

Define $+y \uparrow$ up.

$(F_{Net})_y = 0$




$(F_{Net})_y = 0 = n_{bm} - n_{tm} - mg = 0$

$n_{bm} = n_{tm} + mg > n_{tm} > mg$

# Team Up Question 3

Trick question!

Three books are stacked on top of each other.

They are moving at constant velocity because a person is pulling the bottom book.

How many forces act on the middle book now? Ignore air.

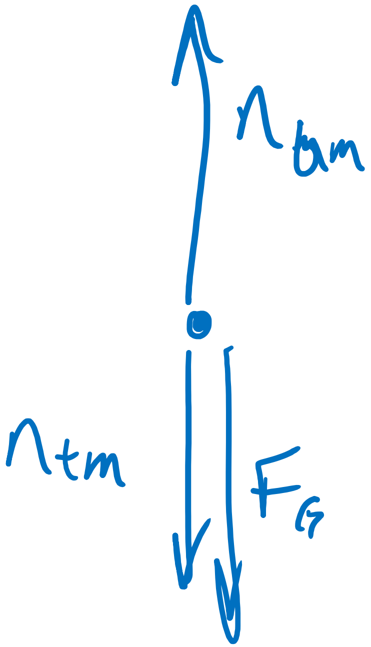
A. 1

B. 2

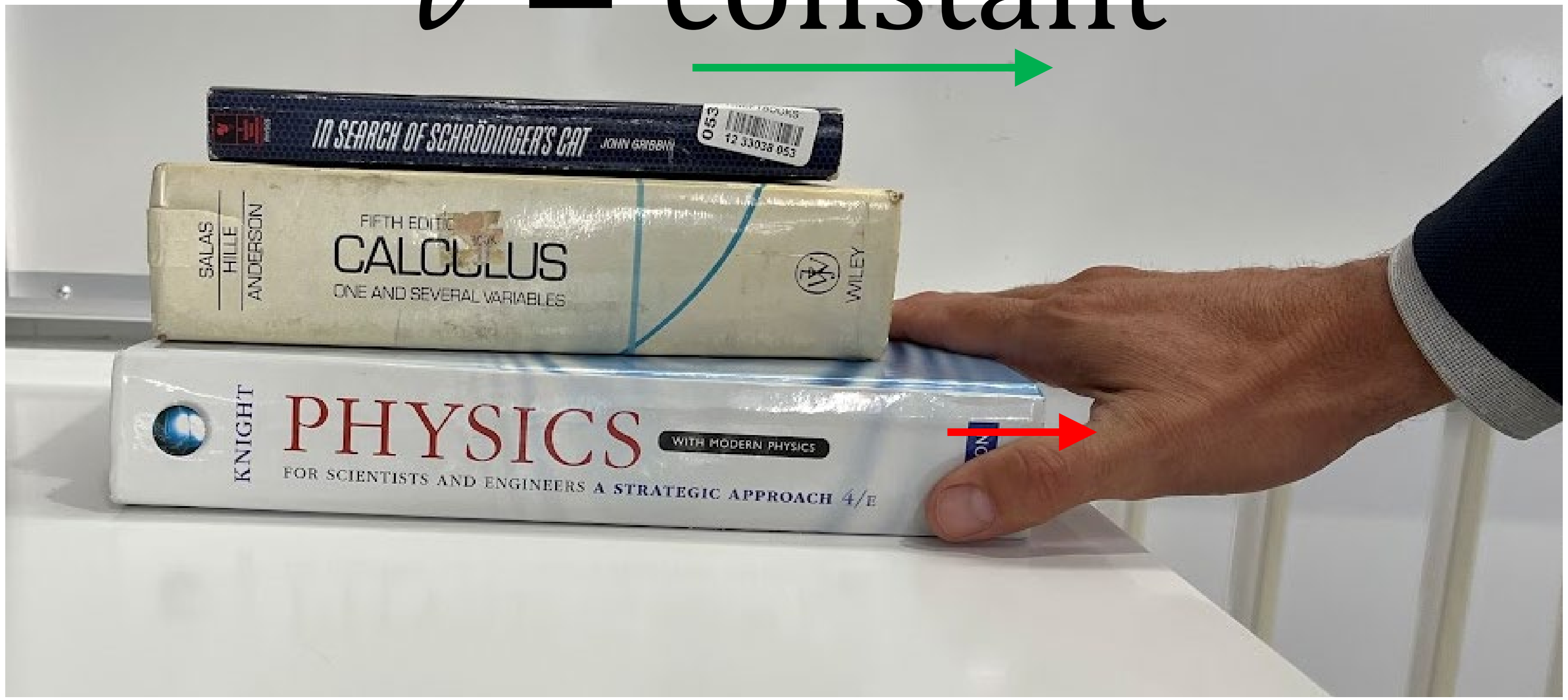
C. 3

D. 4

E. 5




$\vec{v}$ = constant



# Team Up Question 4

Three books are stacked on top of each other.

They are speeding up together at constant acceleration because a person is pulling the bottom book.

How many forces act on the middle book now? Ignore air.

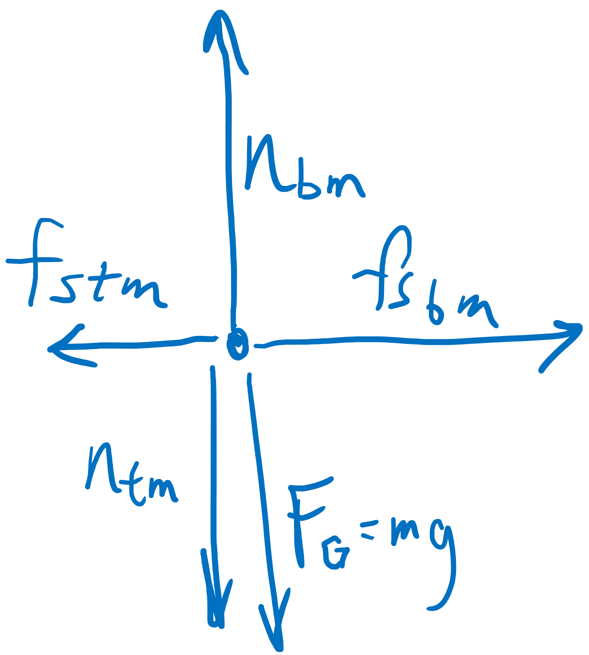
A. 1

B. 2

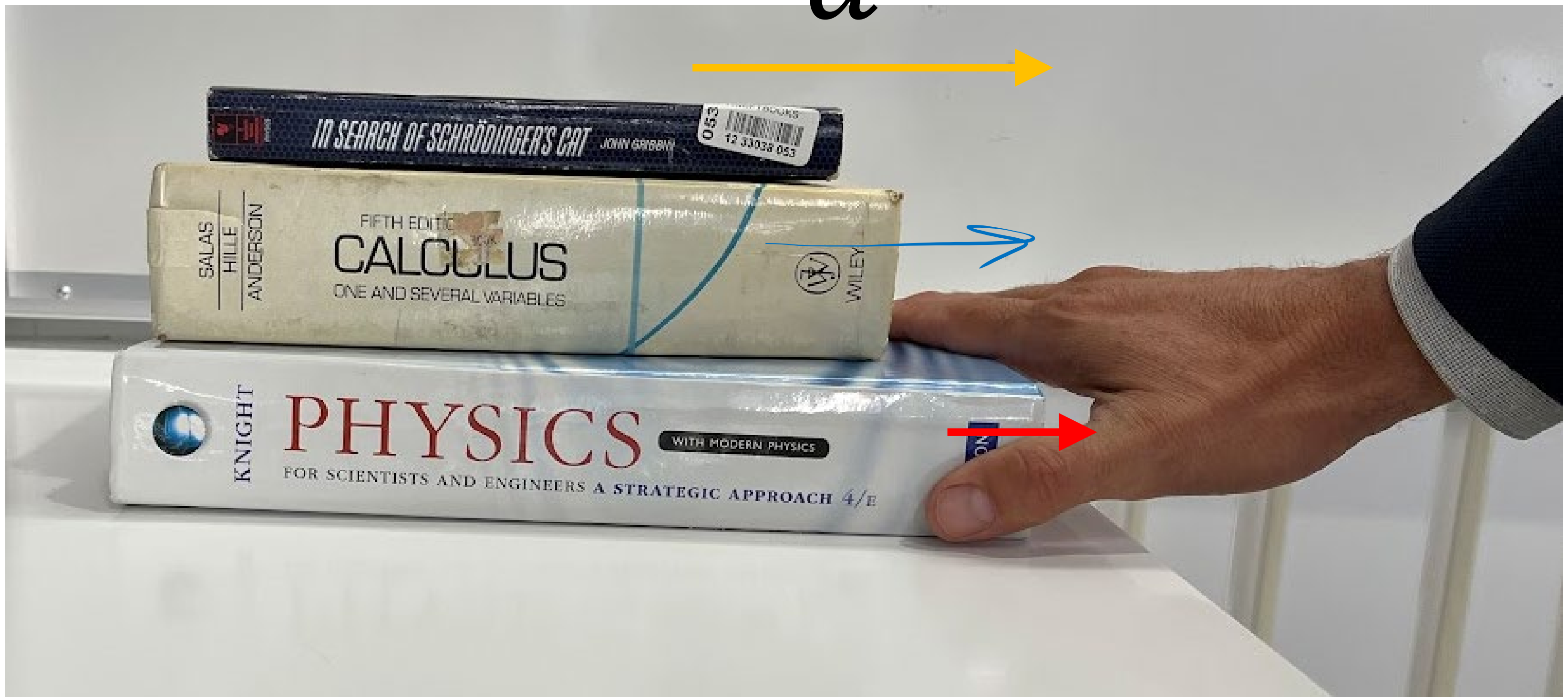
C. 3

D. 4

E. 5




$\vec{a}$



# Ye Old Elevator Example

A box rests on a scale in an elevator. When the elevator is at rest, the scale reads 40 N.

What does the scale read (higher/lower/same) when the elevator:

(a) starts moving up?

(b) moves up at steady speed?

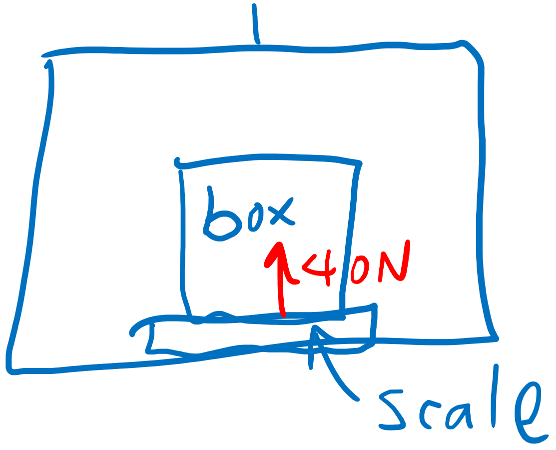
(c) moves up but slows down?

Hints: DRAW A FREE BODY DIAGRAM!

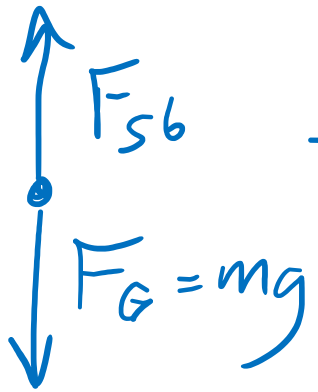
Is there acceleration?

Remember: The NET FORCE must be in the direction of the acceleration.

Newton's 2nd Law.




At rest:




Define + = up

$a = 0$

$\Rightarrow F_{Net} = 0 = F_{sb} - mg = 0$

$F_{sb} = mg = 40\ N$

(a) acceleration is up.

$a > 0$

$F_{Net} = F_{sb} - mg > 0$

$F_{sb} > mg > 40\ N$

higher

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Is there acceleration?

Remember: The NET FORCE must be in the direction of the acceleration.

(b) $\vec{a} = 0$ ← steady

$F_{sb} = 40\ N$ same

---

(c) slowing down means acceleration is opposite velocity $\vec{v} > 0$

$a < 0$

$F_{net} = F_{sb} - mg < 0$

$F_{sb} < 40\ N$, lower

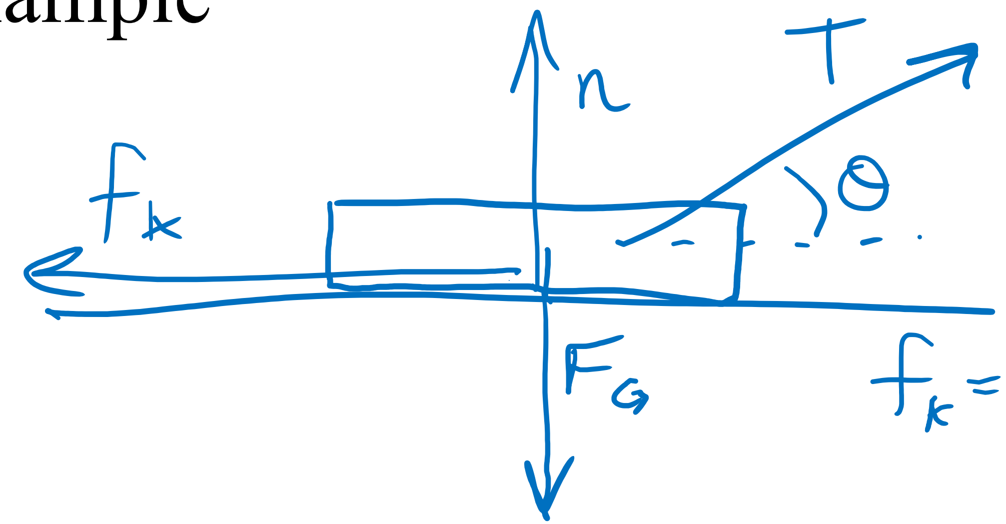
# Ye Old Sled Example

You pull a sled across grass by pulling a rope.
The rope is at an upward angle (not horizontal).
If the angle of the rope increases from 0° to 90° (as the sled is sliding forward), what happens to the other forces? (increase / decrease / stay the same)

Hints: DRAW A FREE BODY DIAGRAM!

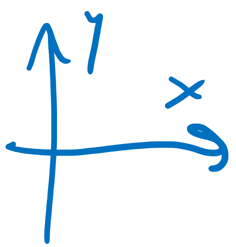
Define *x* and *y* axes so that acceleration has a zero component in one of these directions.

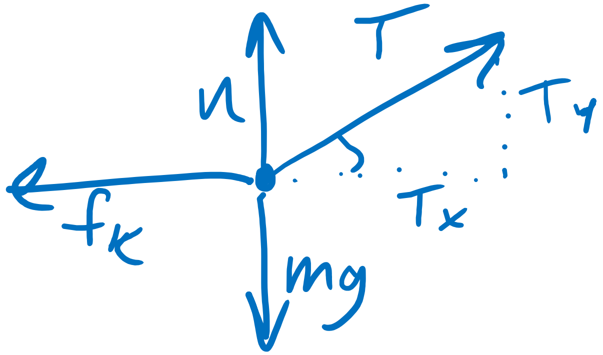
If $a_y = 0$, for example, then the forces must balance in the *y*-direction.




$f_k = \mu_k n$

Define




acceleration could be horizontal, but not vertical:

$a_y = 0$

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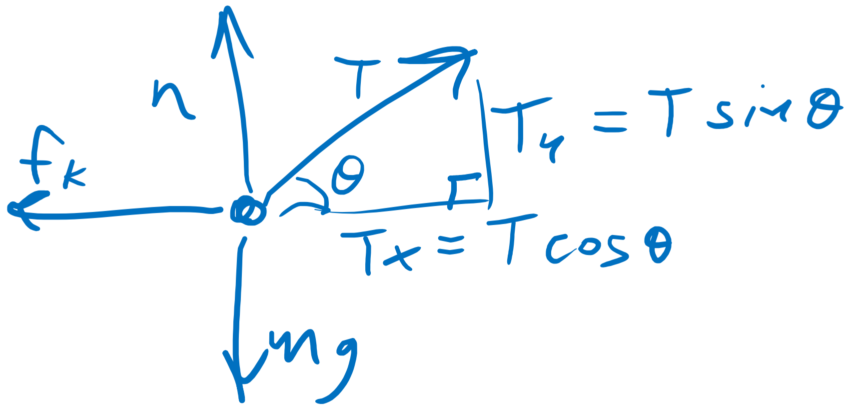


$$(F_{net})_x = T\cos\theta - f_k$$

$$(F_{Net})_x = m a_x = T\cos\theta - \mu_k n$$

$$(F_{Net})_y = 0 = n + T\sin\theta - mg$$

$$\Rightarrow n = mg - T\sin\theta$$

increase $\theta$, from $0 \to 90°$, increase $\sin\theta$

decrease $n$.

$f_k = \mu_k n$, so you decrease $f_k$

(Assuming $T$ is constant)