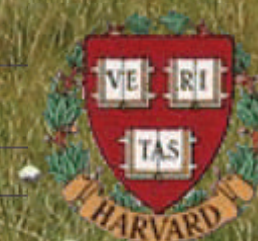




# The make-believe world of real-world physics



Brandeis University  
Waltham, MA, 8 September 2009





*Dear Professor,*

*Dear Professor,*

*I still don't believe heavy  
and light things fall at the same speed.*



*Dear Professor,*

*I still don't believe heavy  
and light things fall at the same speed.  
A feather and a stone, for example.*

*Dear Professor,*

*I still don't believe heavy  
and light things fall at the same speed.  
A feather and a stone, for example.  
You kept saying I'd get it  
if I lived in a vacuum.*



*Dear Professor,*

*I still don't believe heavy  
and light things fall at the same speed.*

*A feather and a stone, for example.*

*You kept saying I'd get it  
if I lived in a vacuum.*

*Do you live in a vacuum?*

Nin Andrews, *Dear Professor* (Subito Press, 2008)

Does physics apply to the real world?



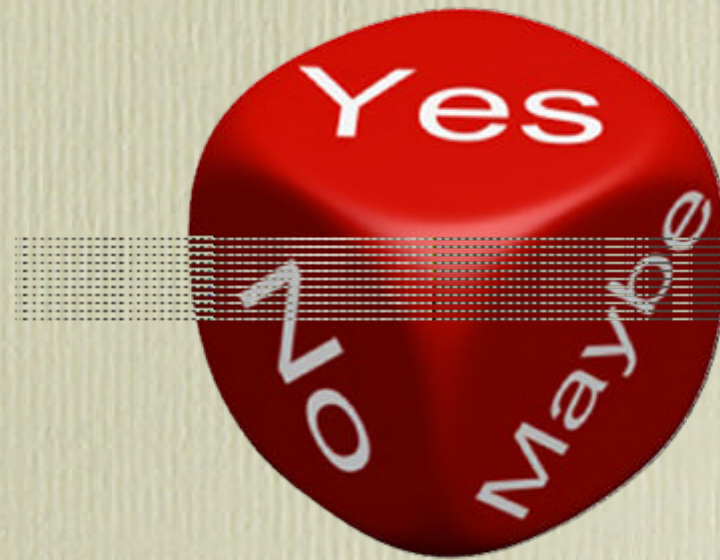


Does physics apply to the real world?



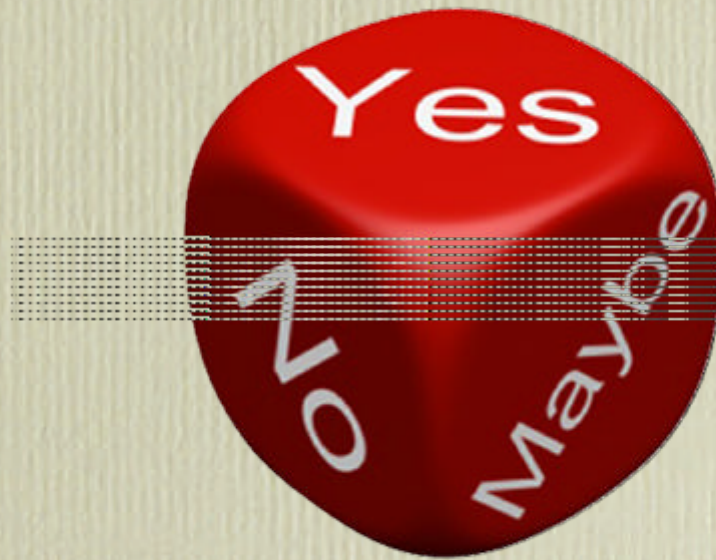
Does physics apply to the real world?

physicists



Does physics apply to the real world?

physicists



lay people

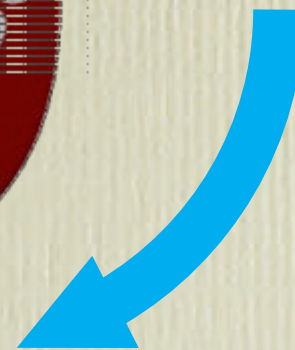


Does physics apply to the real world?

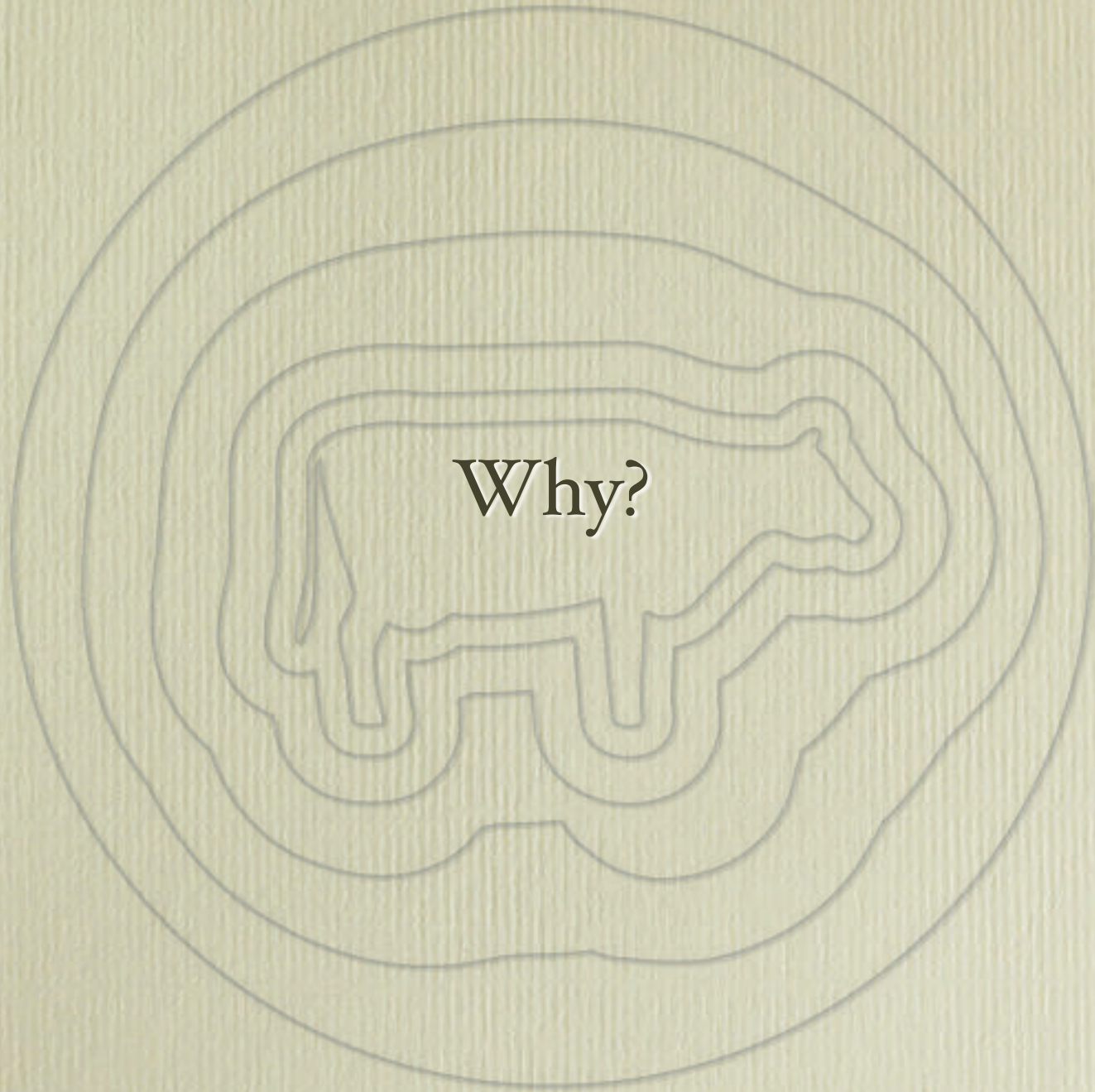
physicists



lay people



students

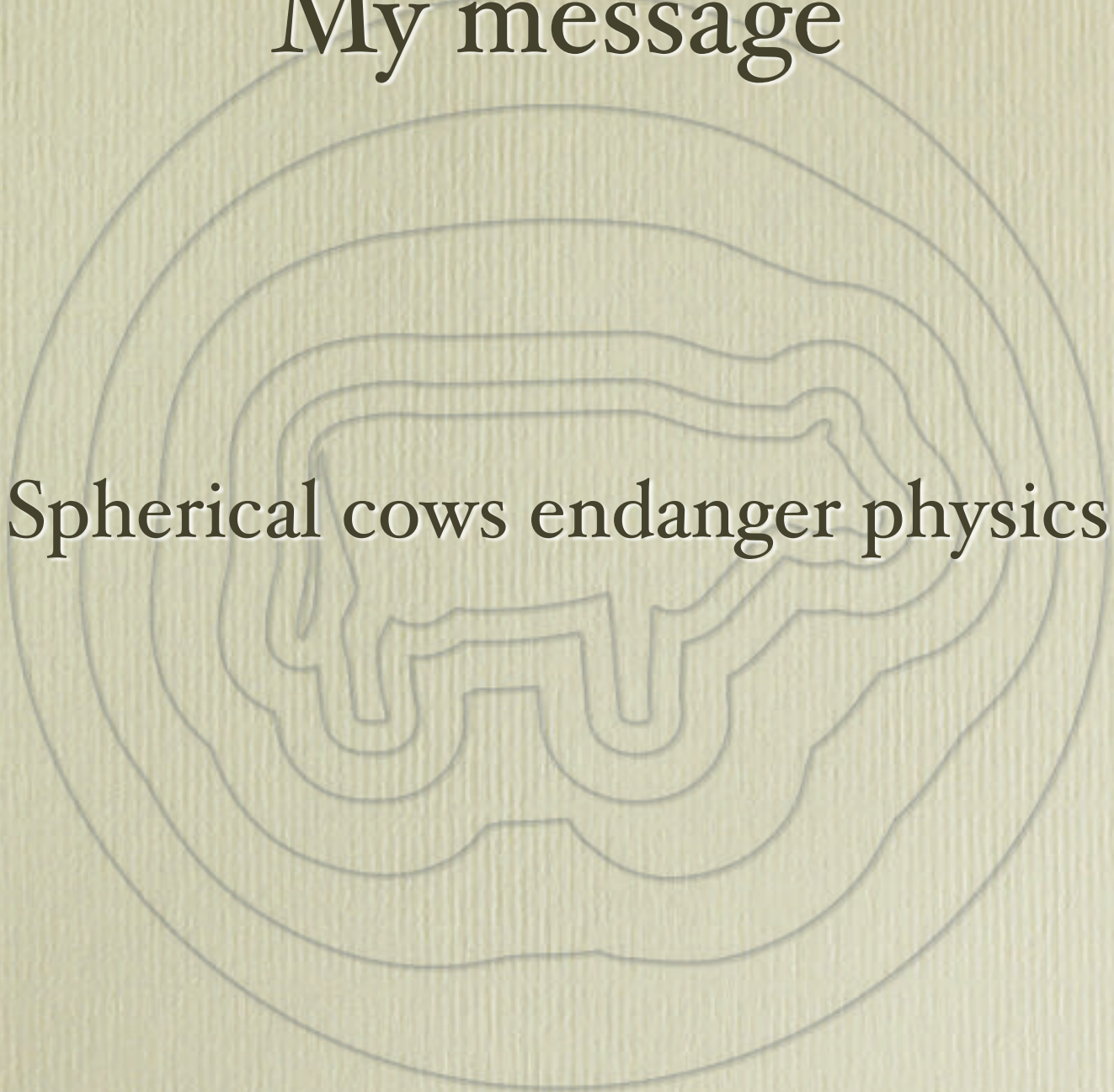


Why?



# My message

Spherical cows endanger physics

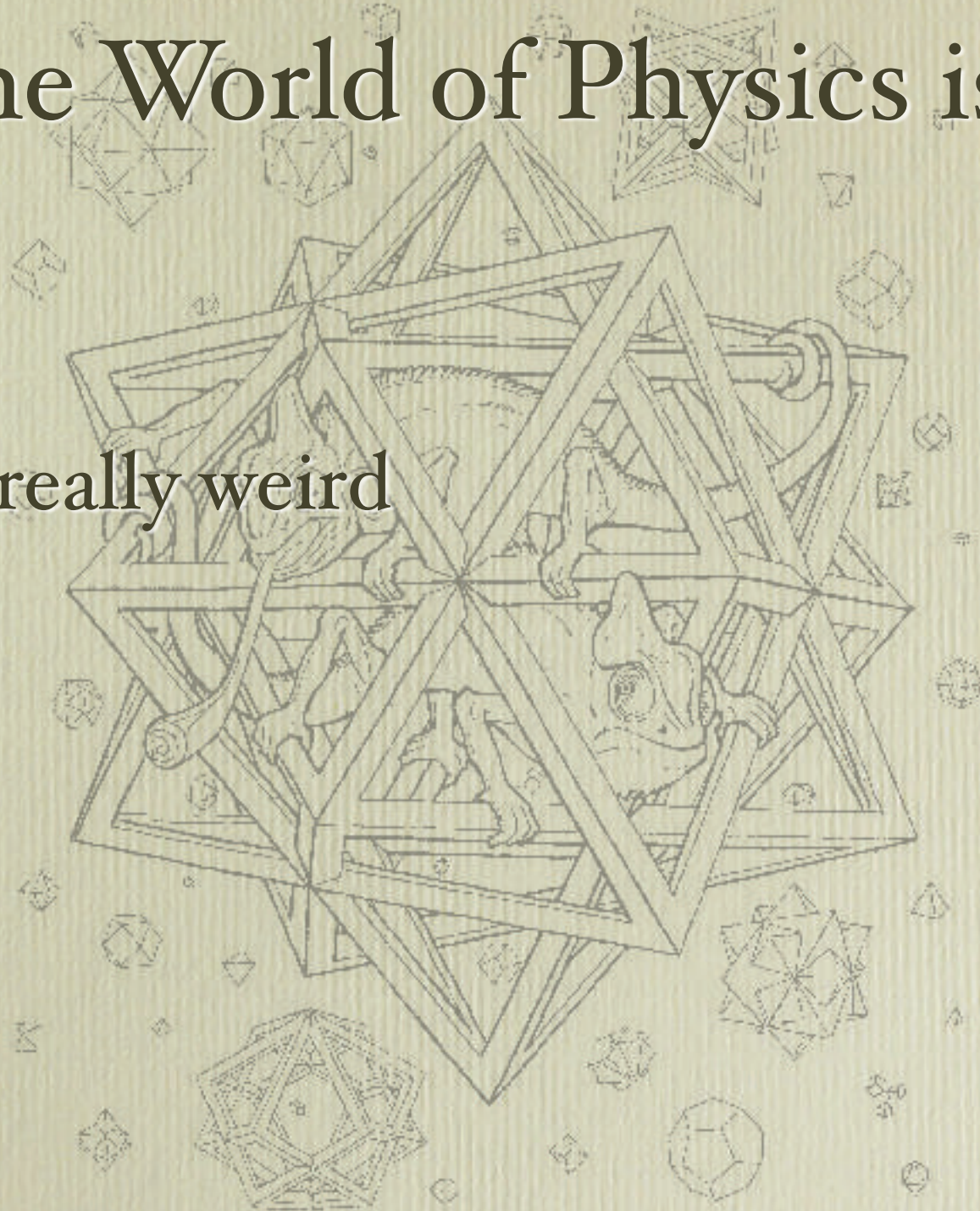




# The World of Physics is...



really weird

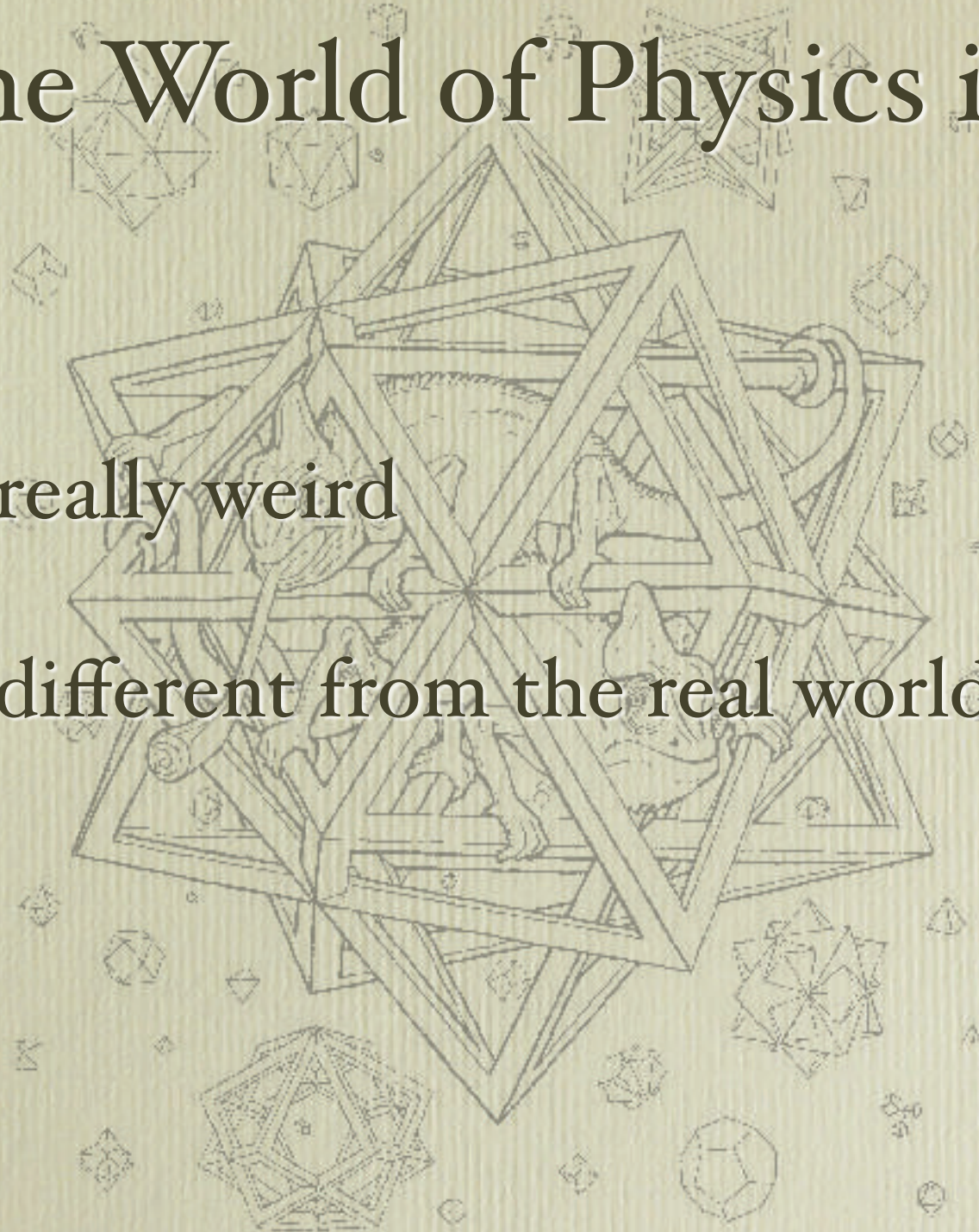




# The World of Physics is...

 really weird

 different from the real world





# The World of Physics is...



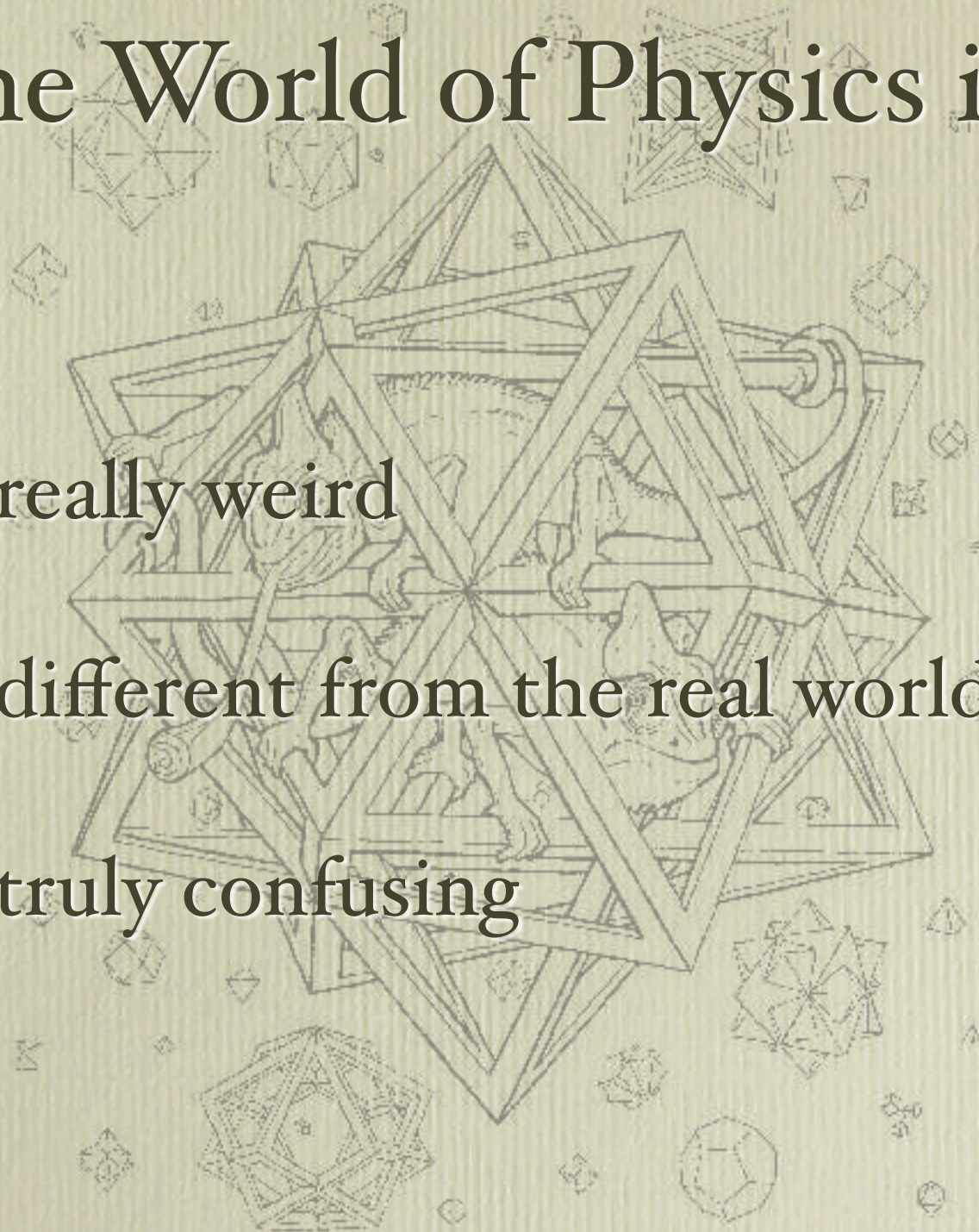
really weird



different from the real world



truly confusing



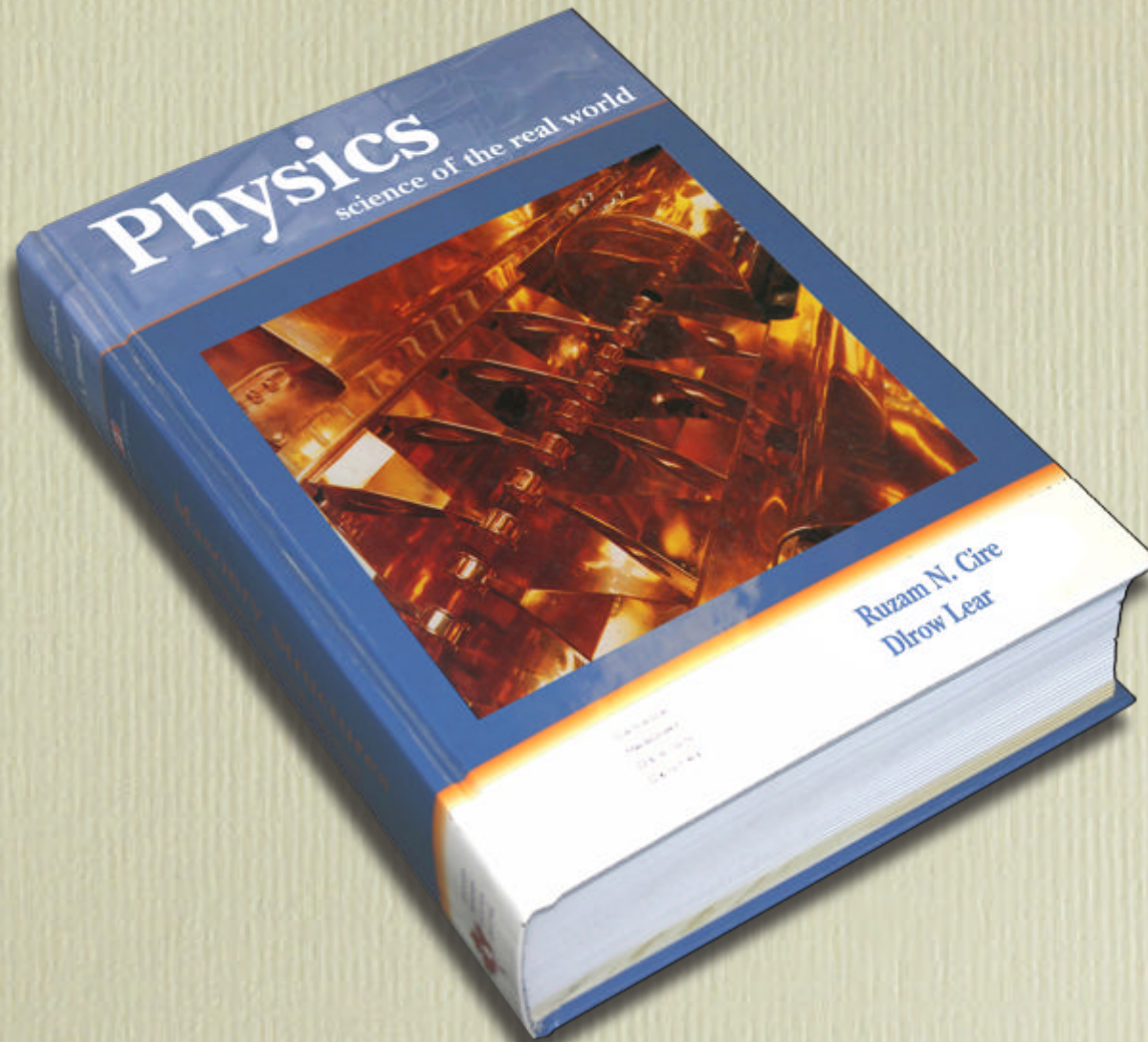


# The weird world of physics



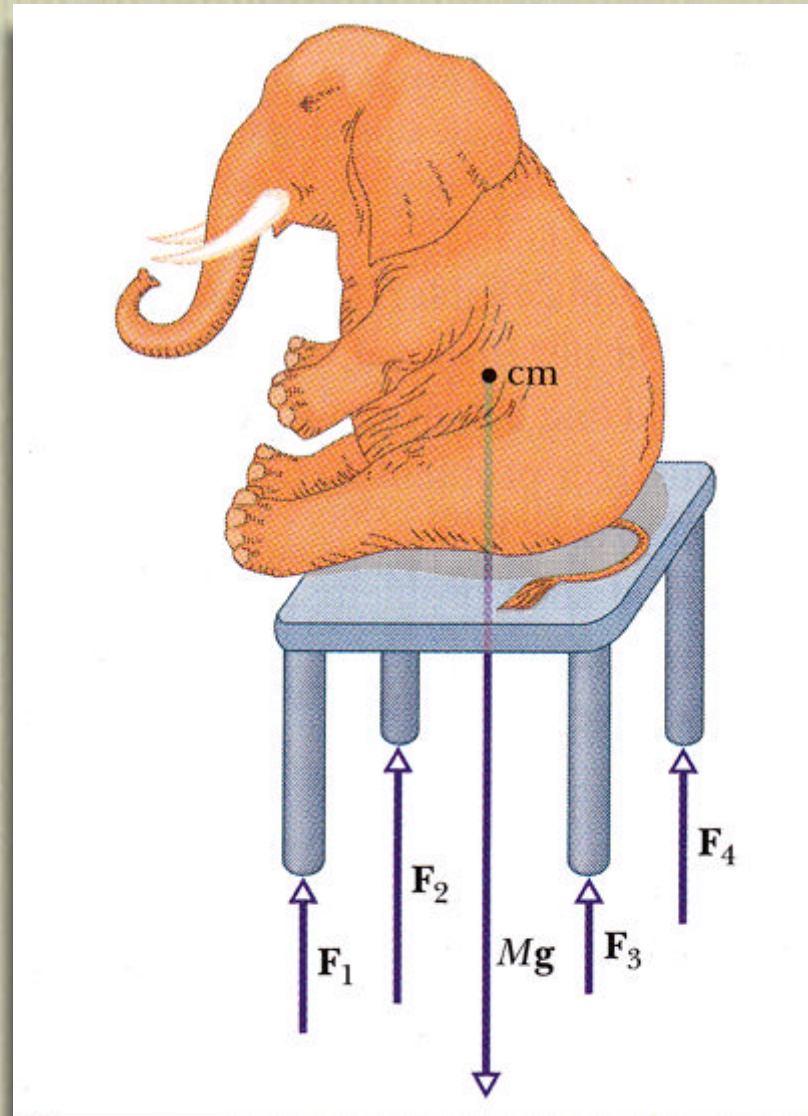


# First impressions



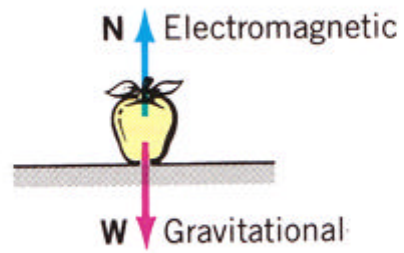


# Table manners

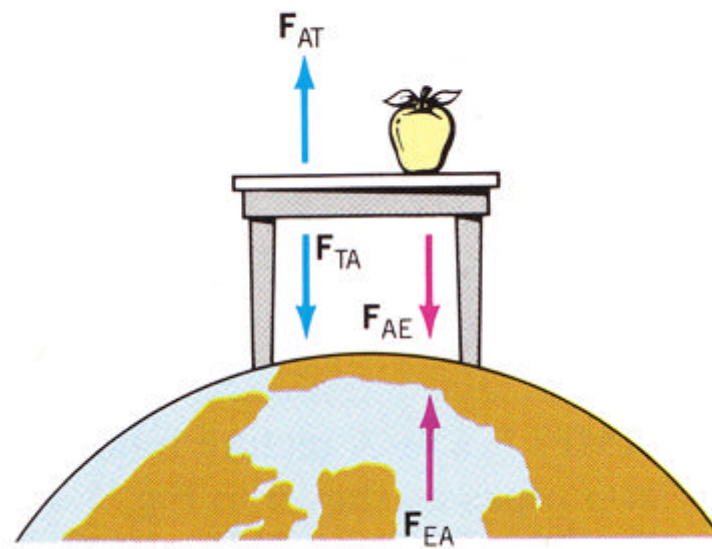




# Table manners



(a)

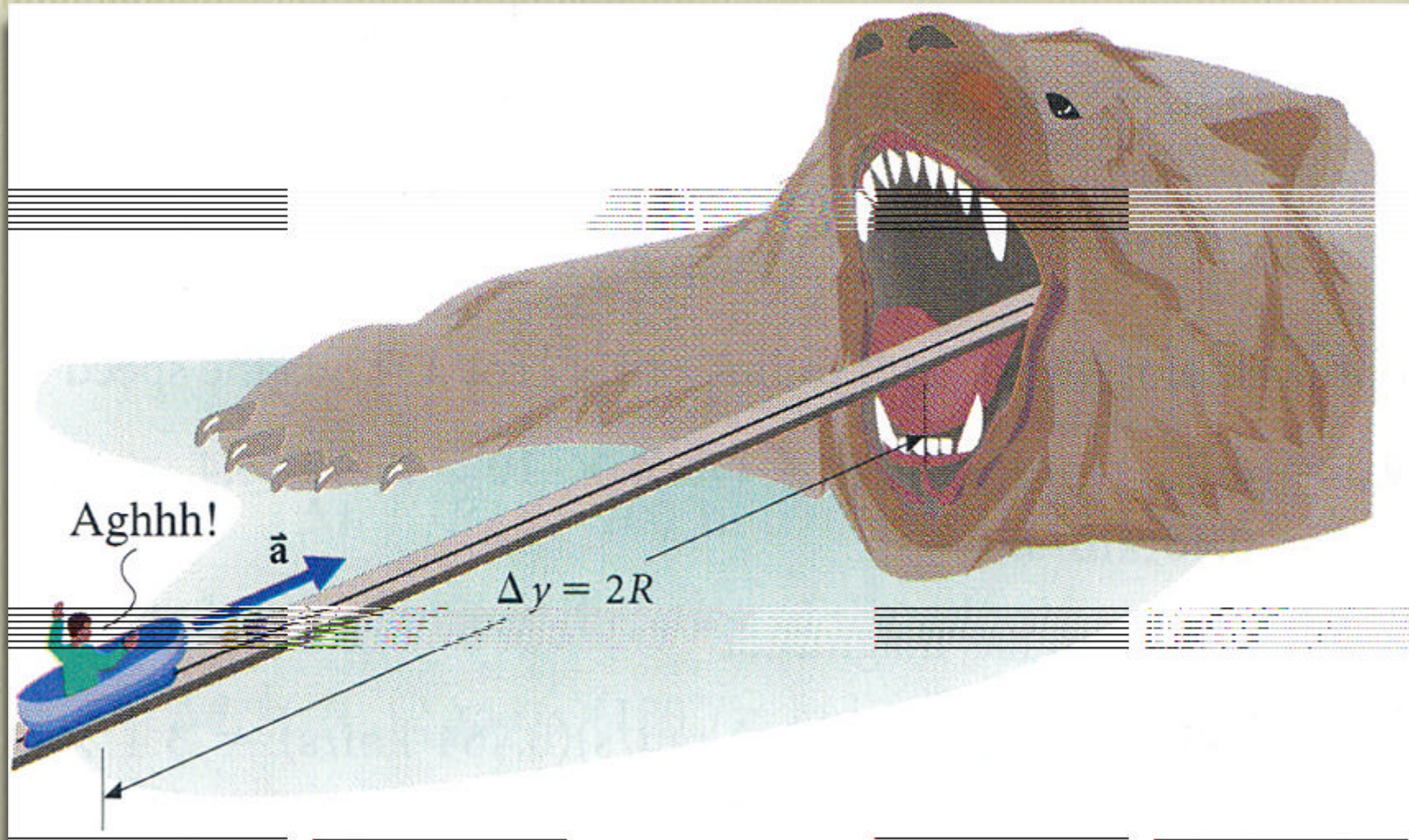


(b)



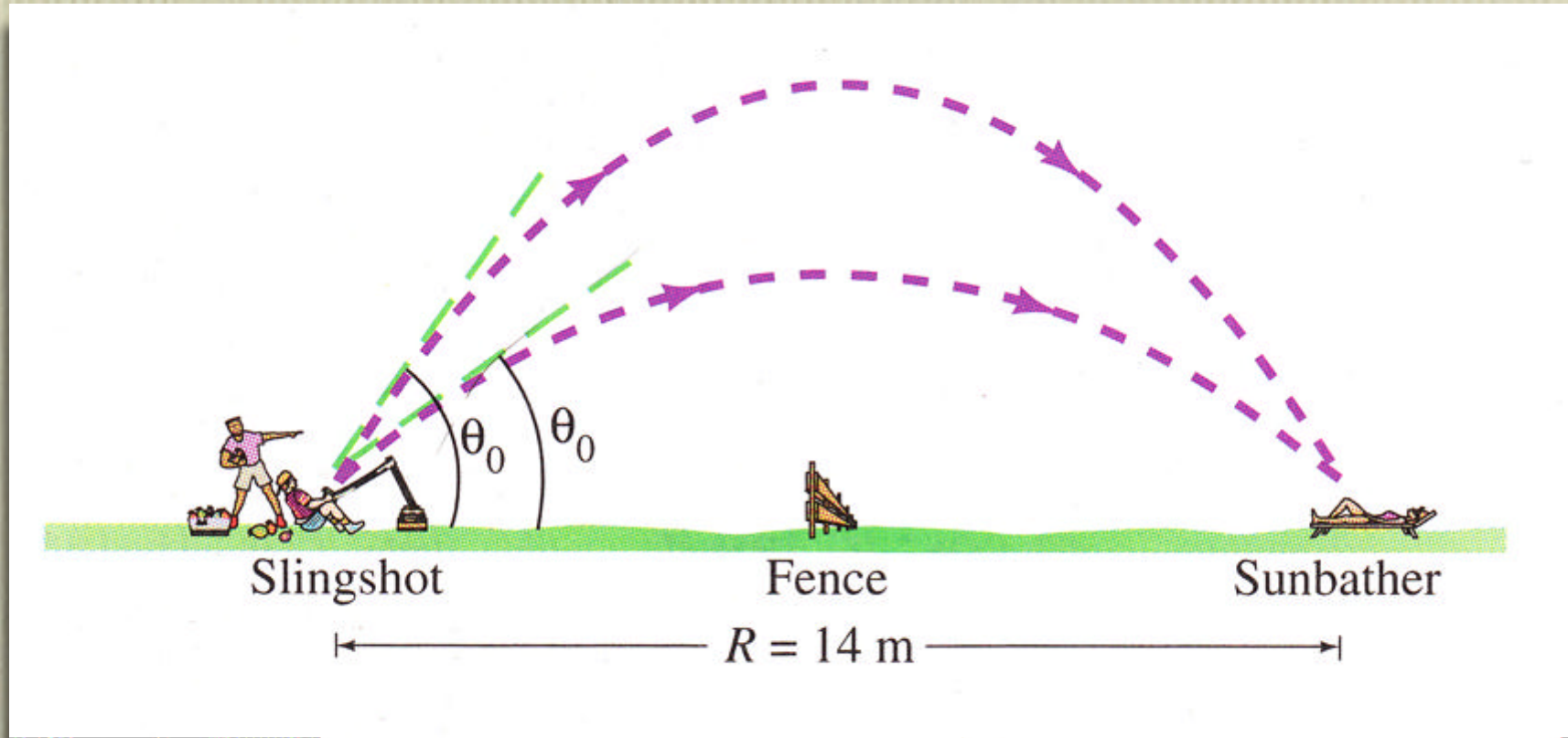


# Leisure time activities

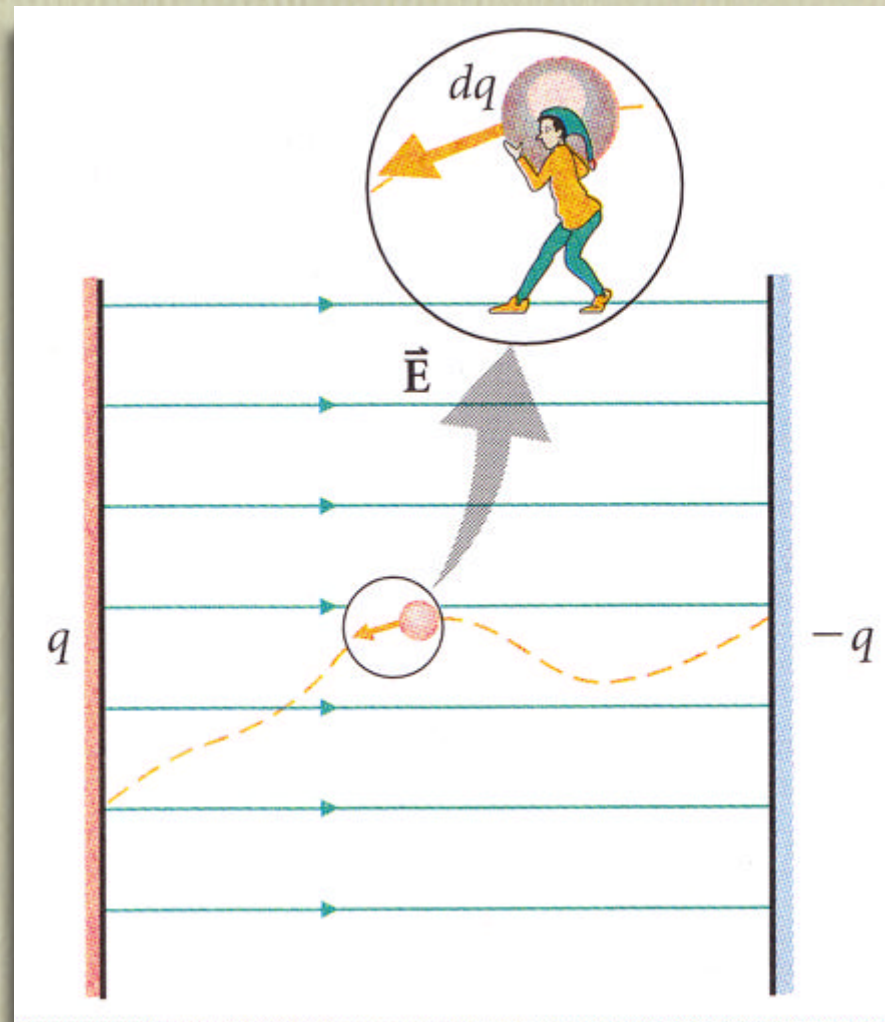




# Leisure time activities



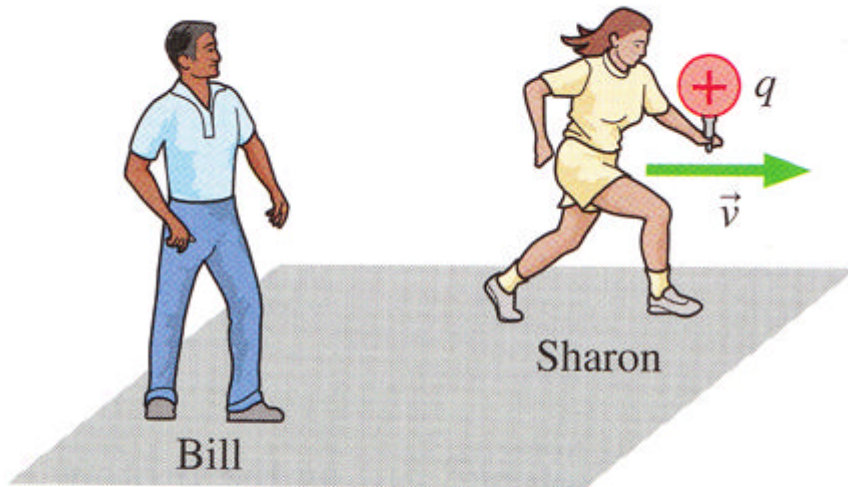
# Leisure time activities





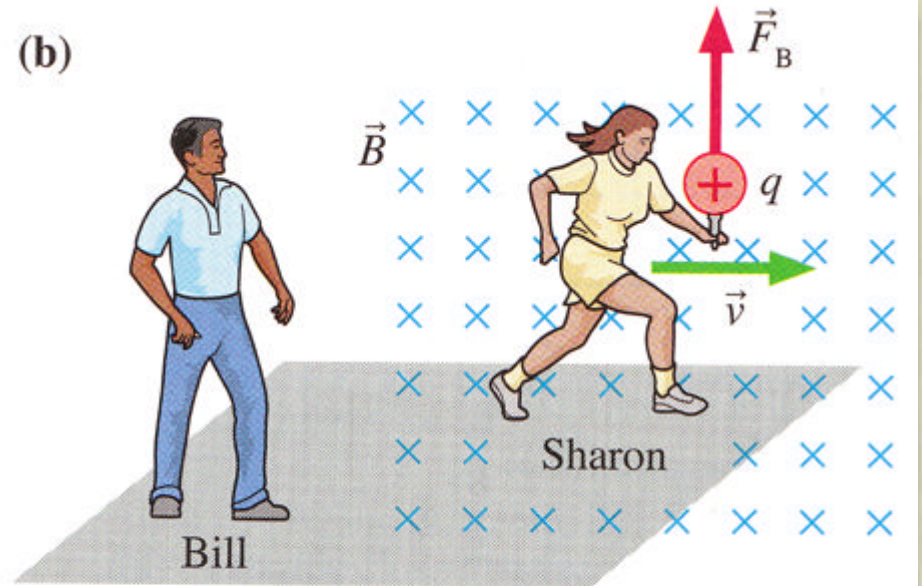
# Leisure time activities

(a)



Charge  $q$  moves with velocity  $\vec{v}$  relative to Bill.

(b)



Charge  $q$  moves through a magnetic field  $\vec{B}$  established by Bill.

**FIGURE 34.6** Sharon carries a charge past Bill.



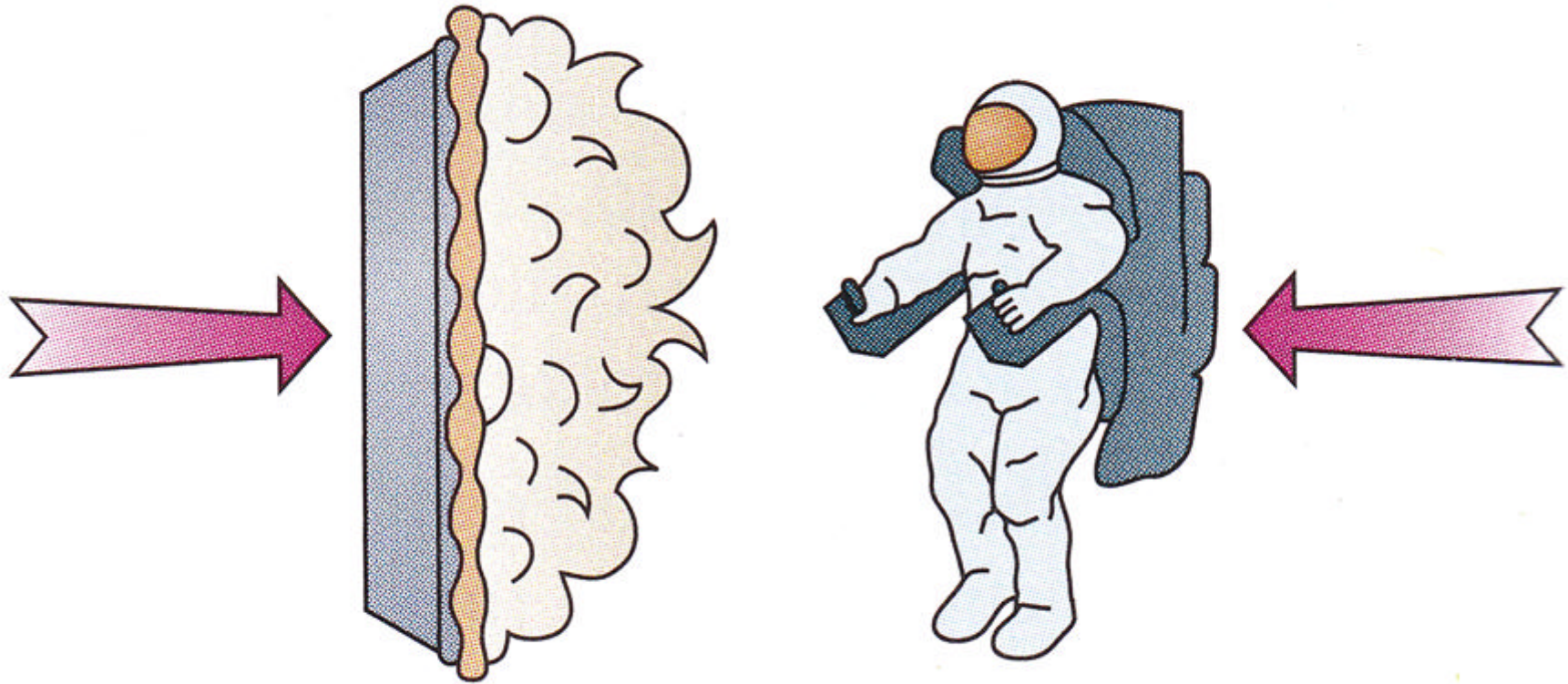


# Leisure time activities



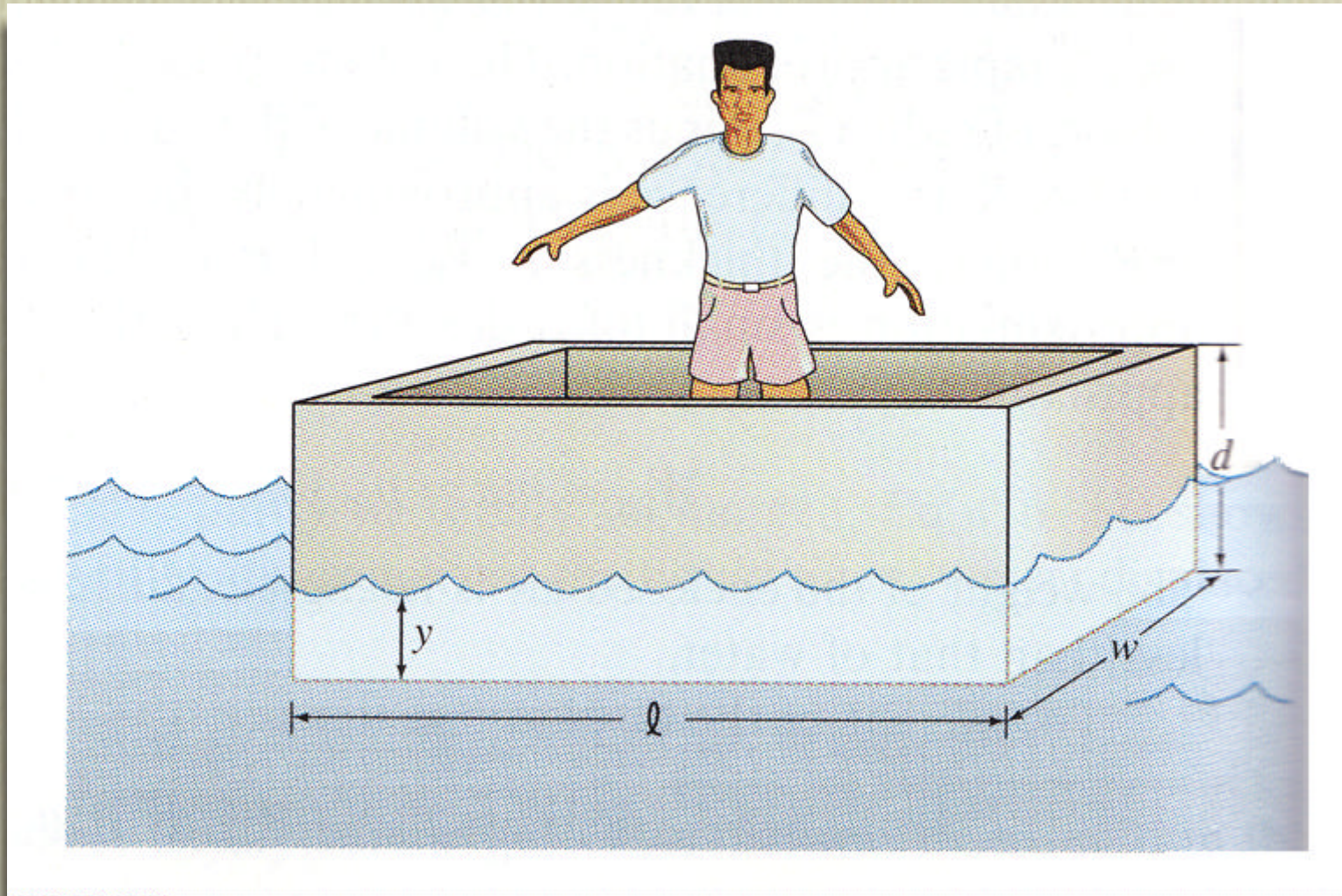


# Leisure time activities



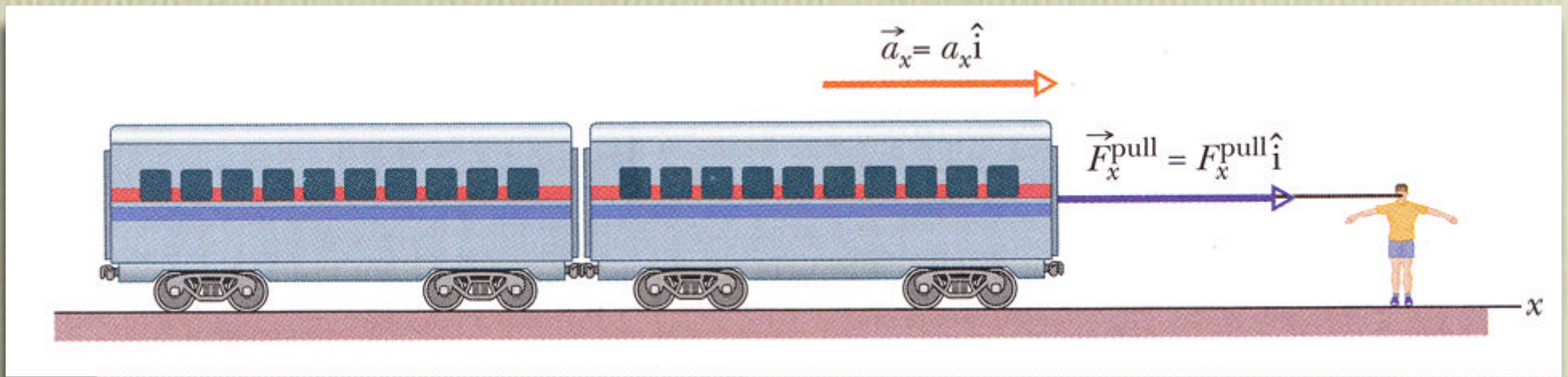


# Leisure time activities





# Leisure time activities



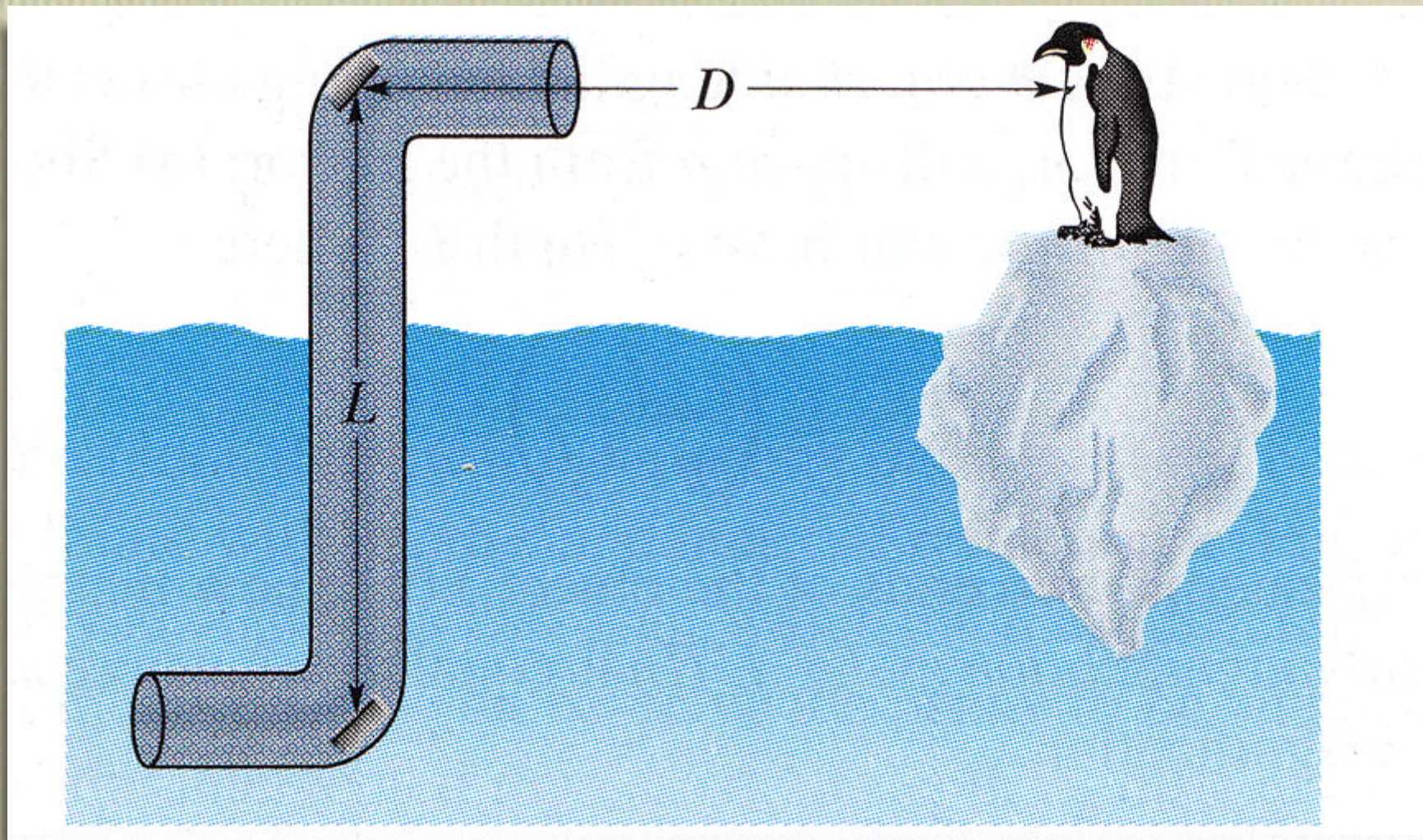


# Fascinations



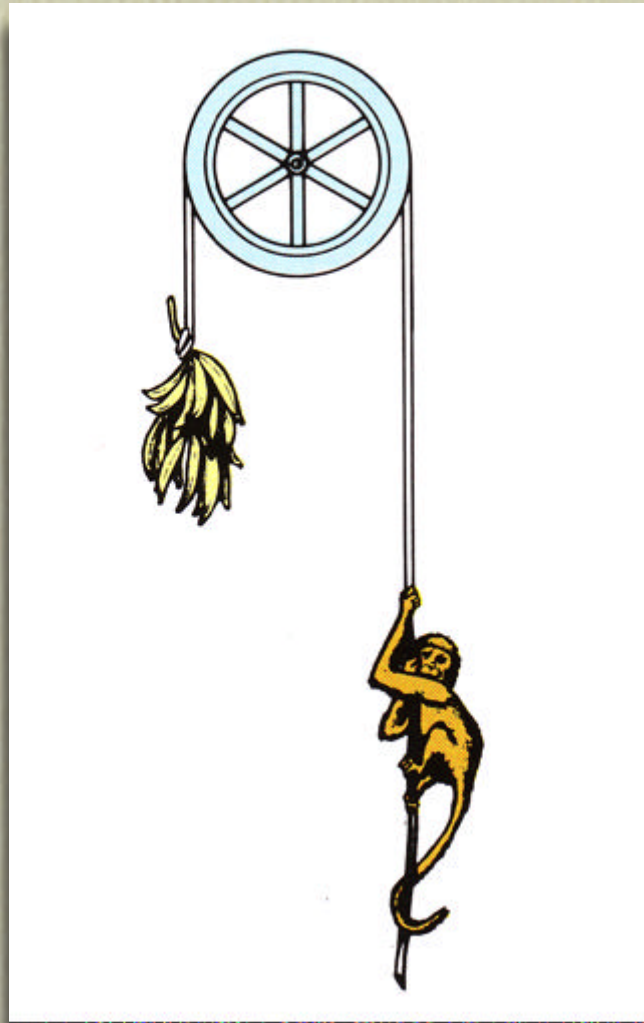


# Fascinations



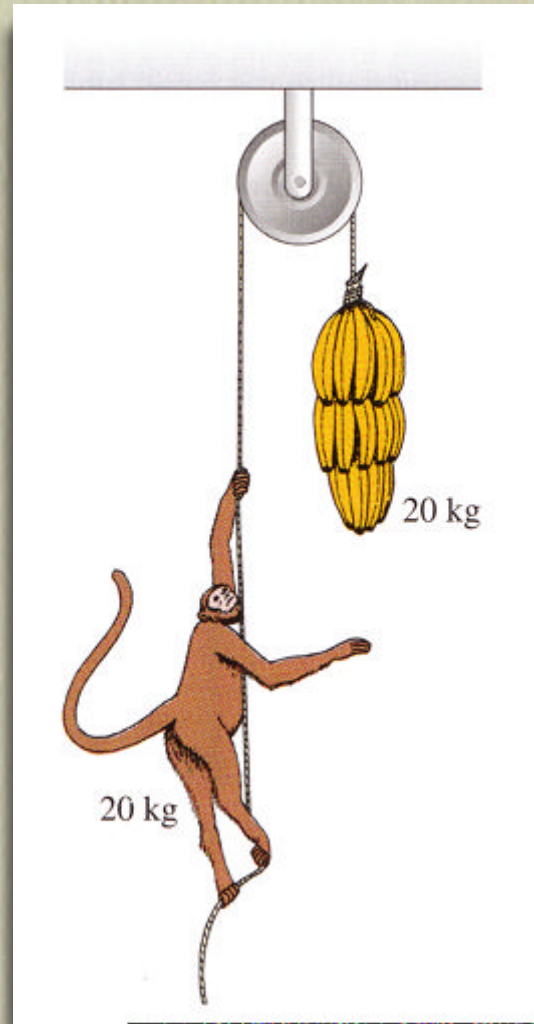


# Fascinations

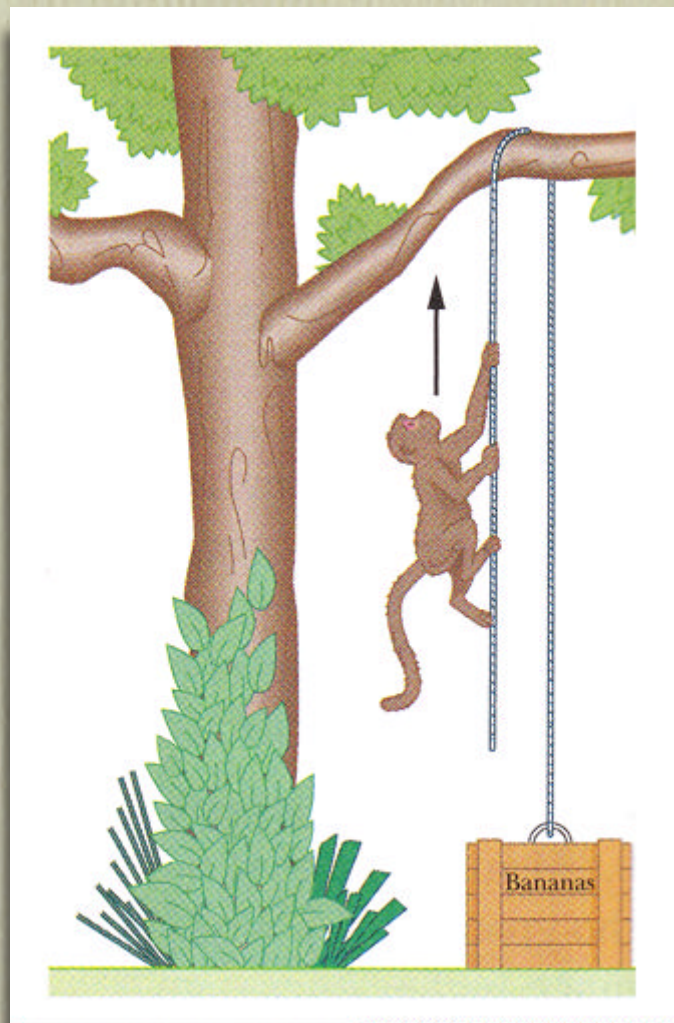




# Fascinations



# Fascinations





# Fascinations

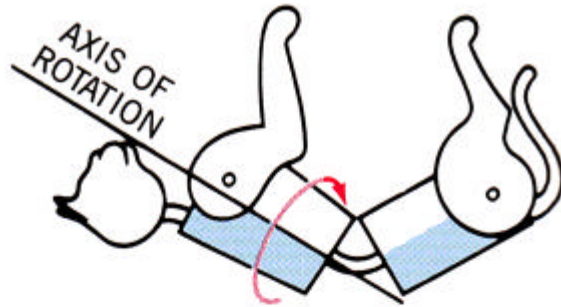


# Spherical cows and...

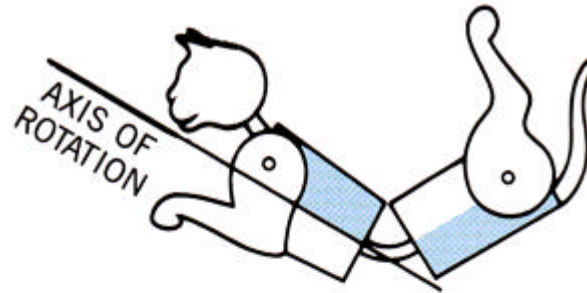




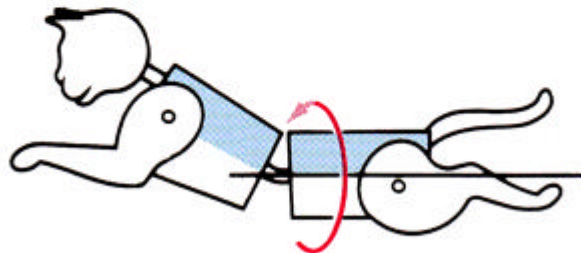
# Spherical cows and...



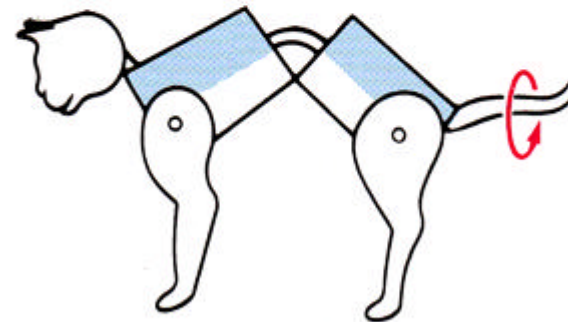
POSITION 1. Flexion, at the waist.  
Fore-part begins to turn.



POSITION 2. Fore-part rotated through  
180°.



POSITION 3. Rear end rotating on  
fore-end.



POSITION 4. Back arched. Legs  
extended for landing.  
Tail circling for "trim."

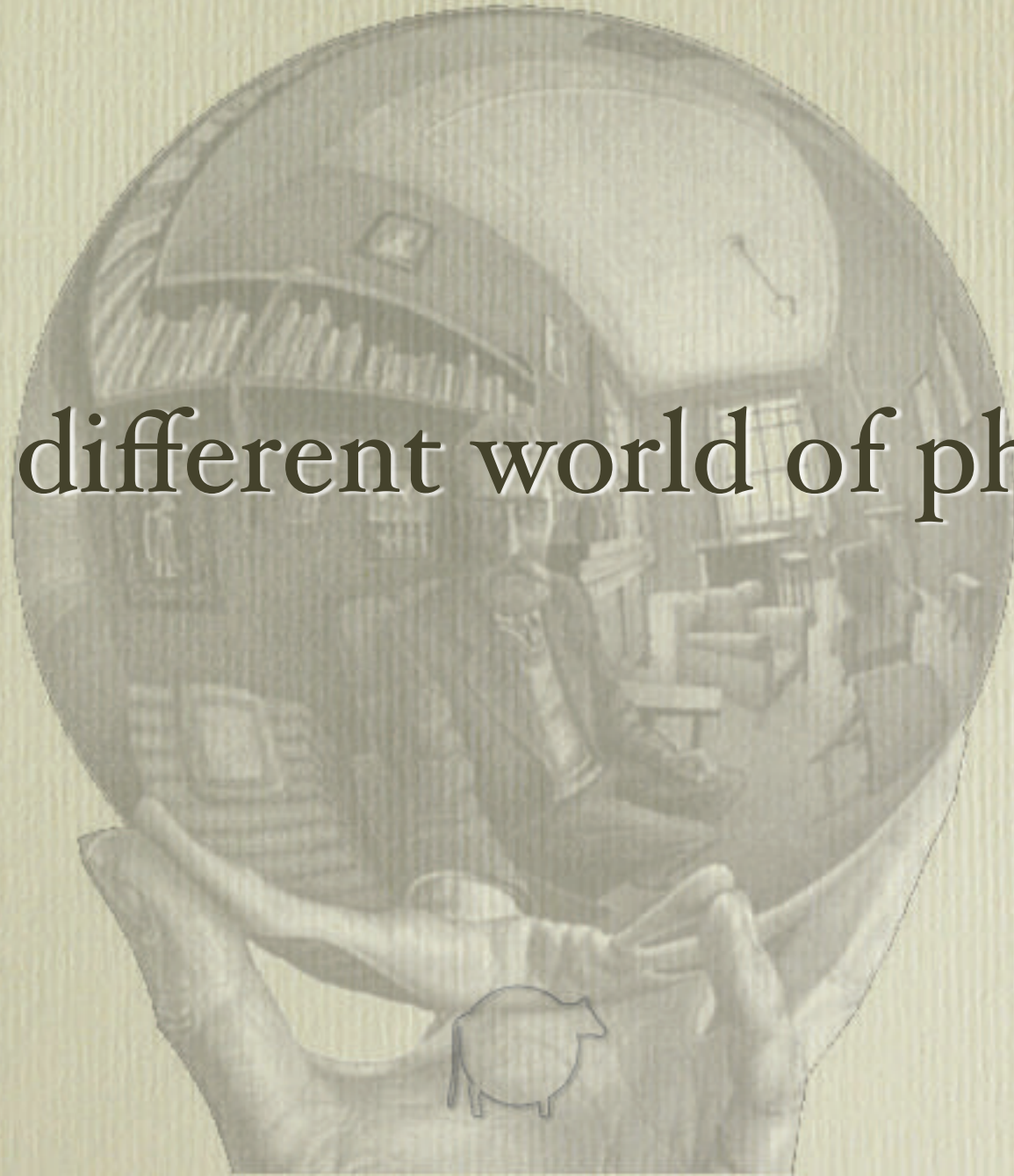


Silly art makes us look weird



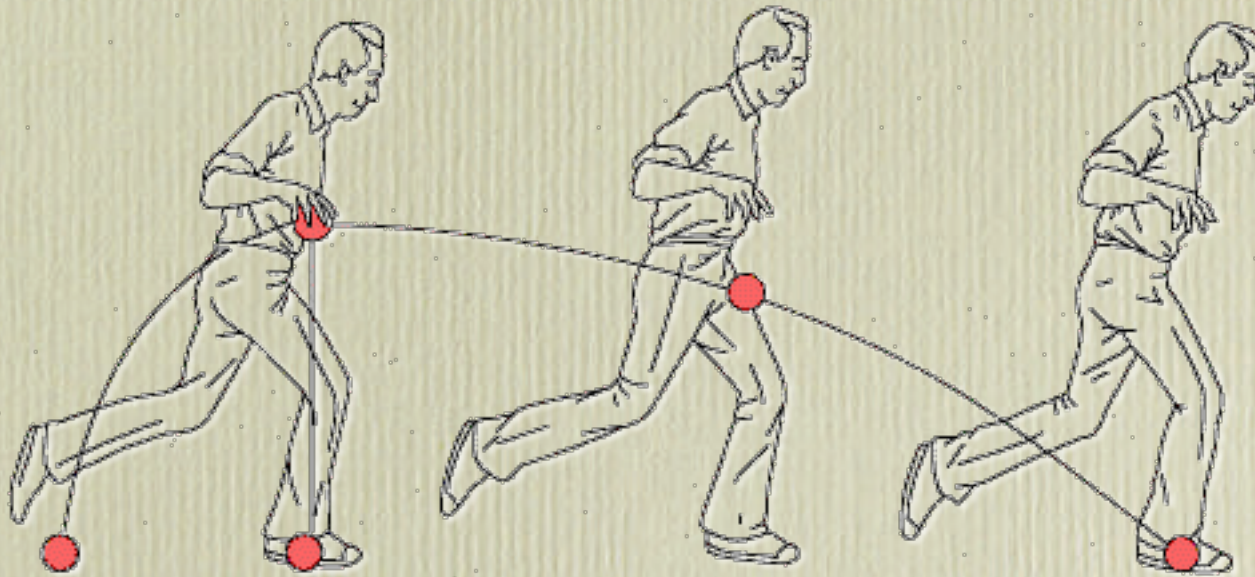


# The different world of physics





# Parabolic motion

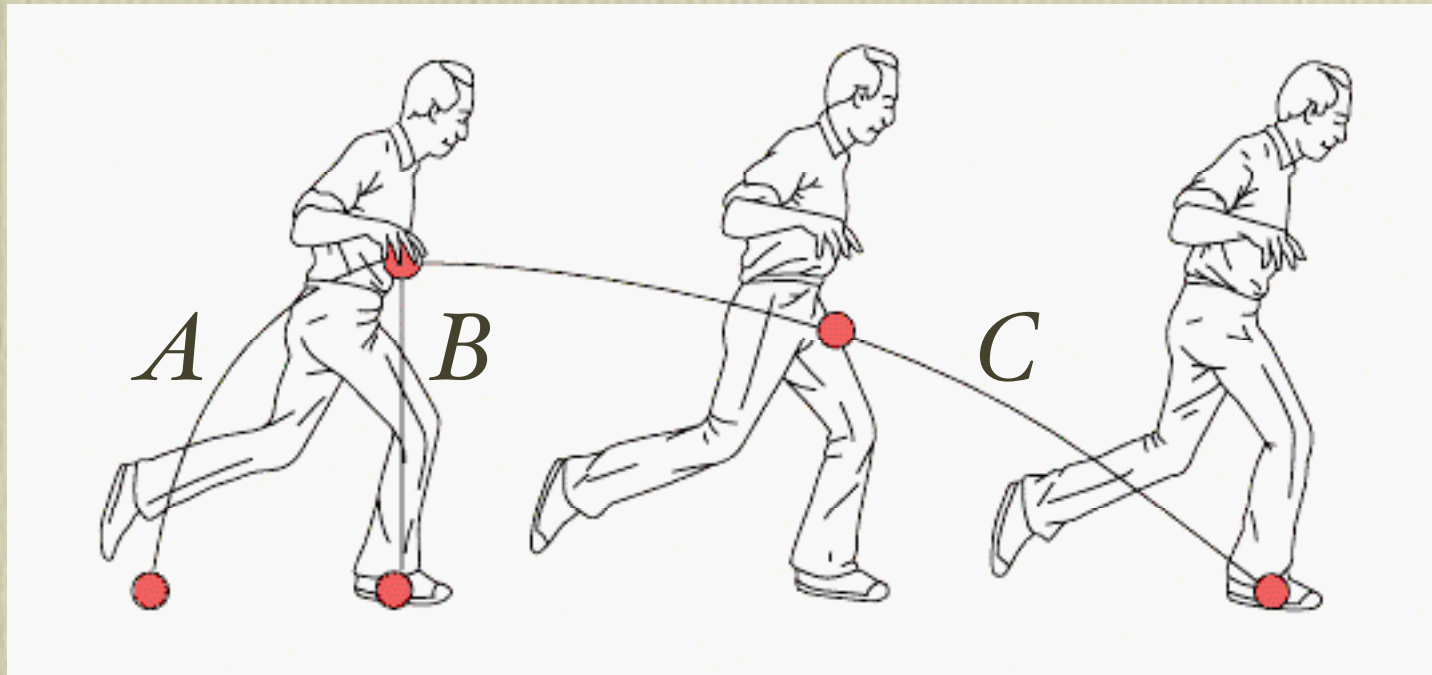


M. McCloskey, *Intuitive Physics*  
Scientific American 248 (1983), pp. 122-130





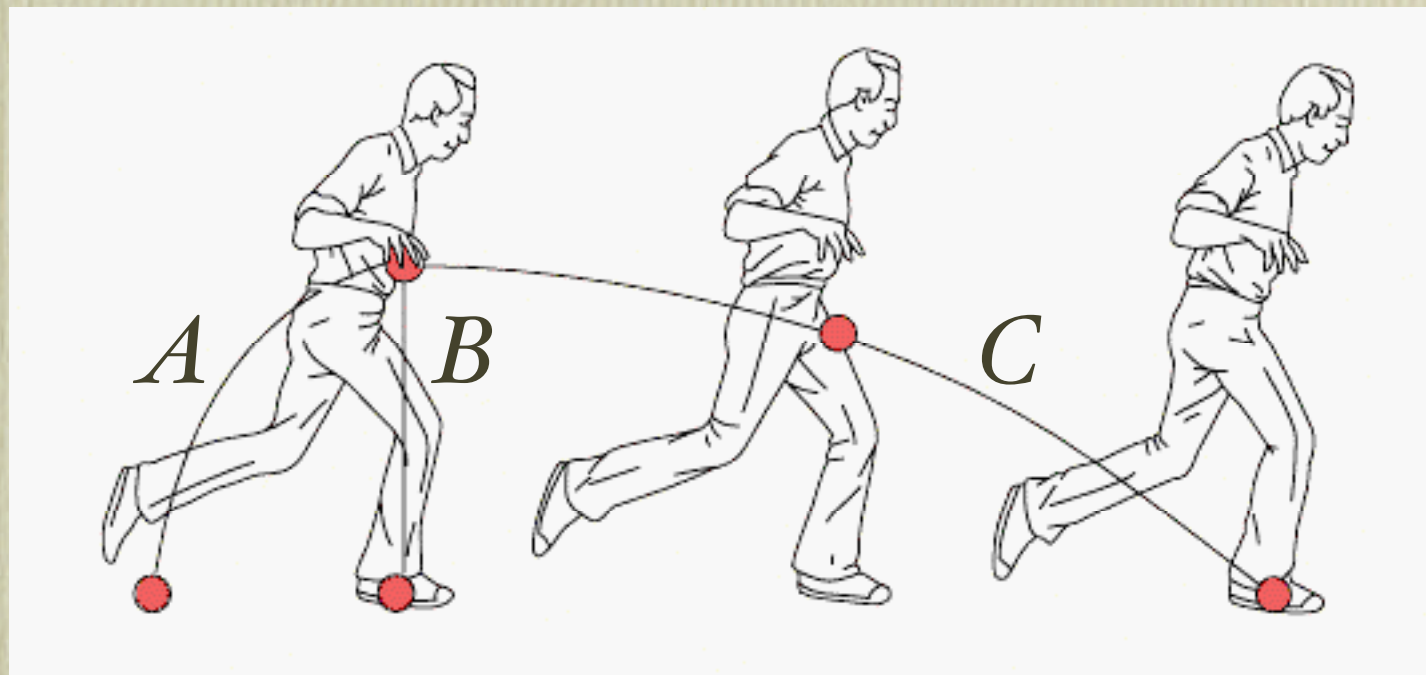
Which of the three paths shown (*A*–*C*) most closely resembles the path taken by the ball?







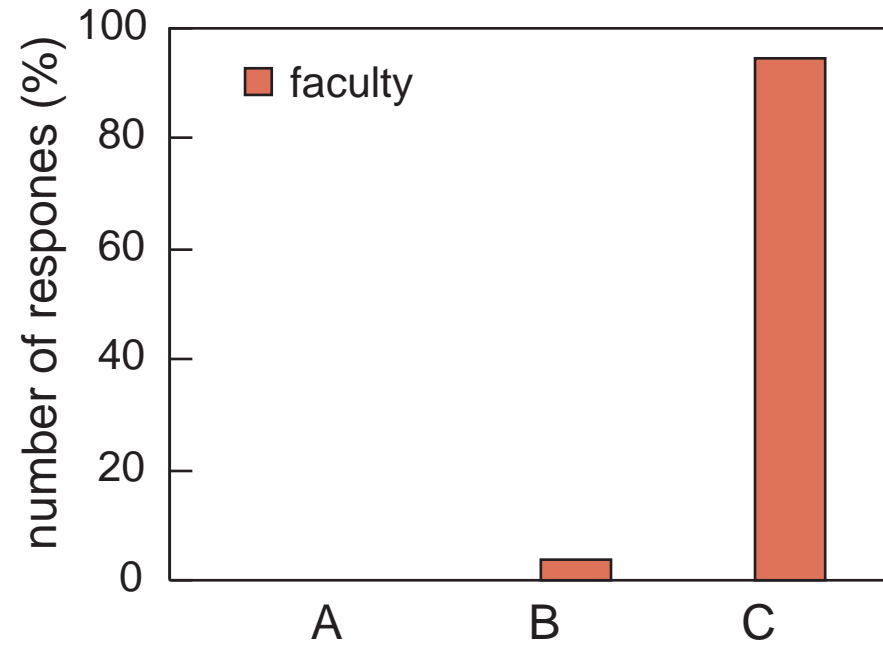
Which trajectory does the lay person select?



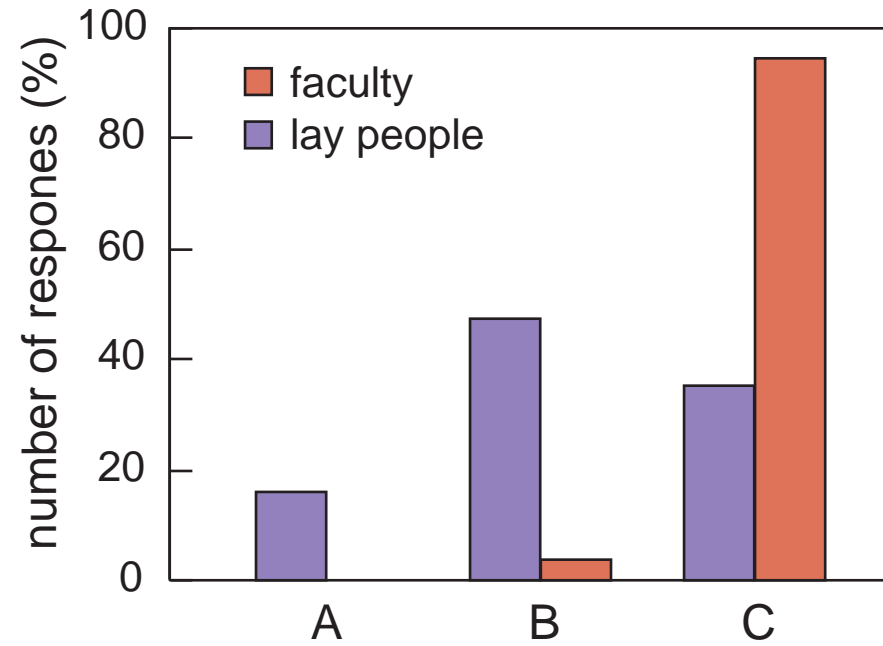




# Predictions



# Predictions







“The ball can’t go that far forward.”





“My eyes can’t lie; I’ve seen B.”



“I’d like to see it.”





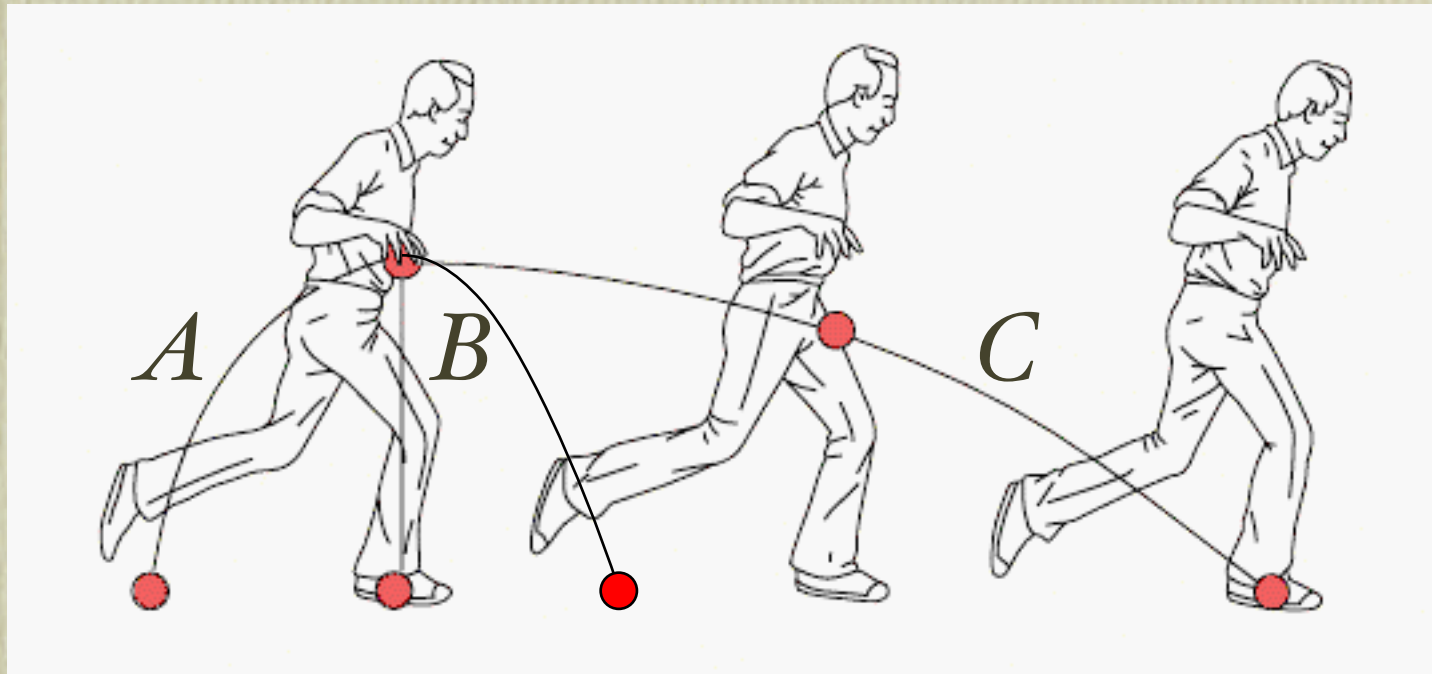
“Give me a proof.”



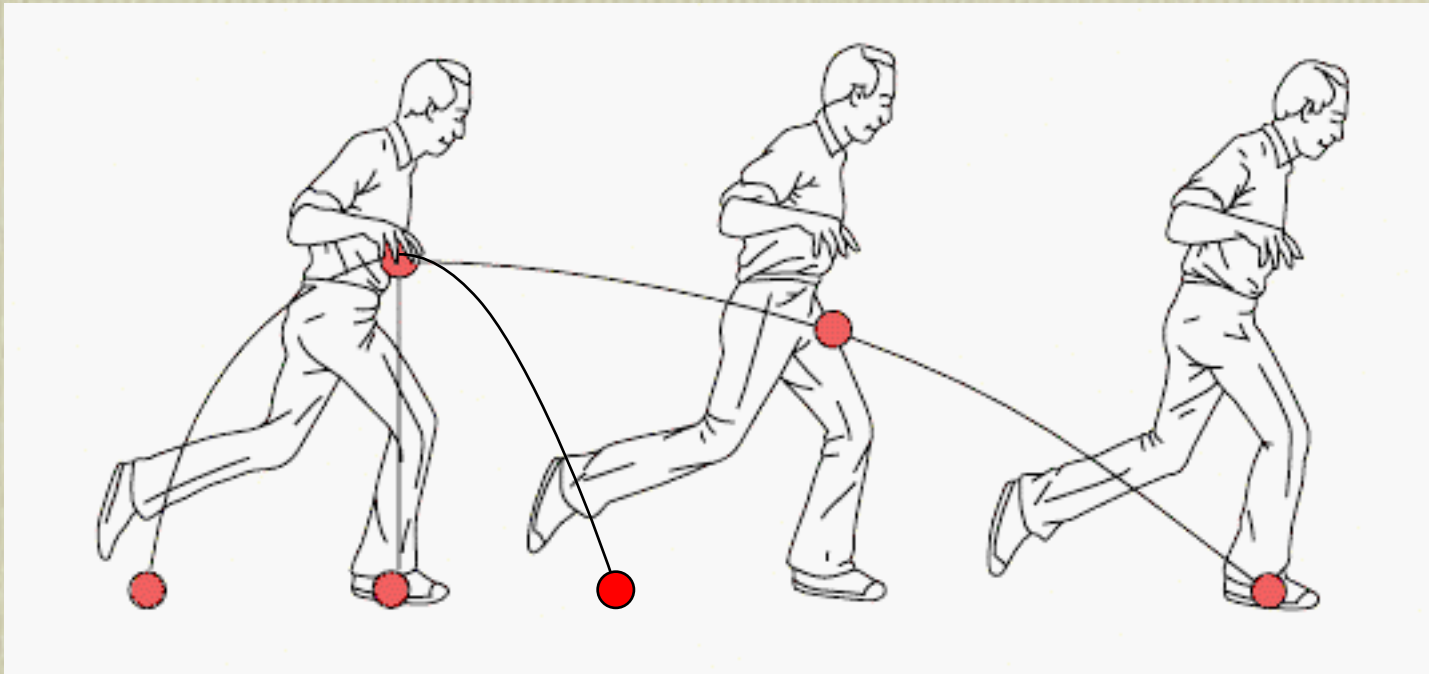




# B is closest!

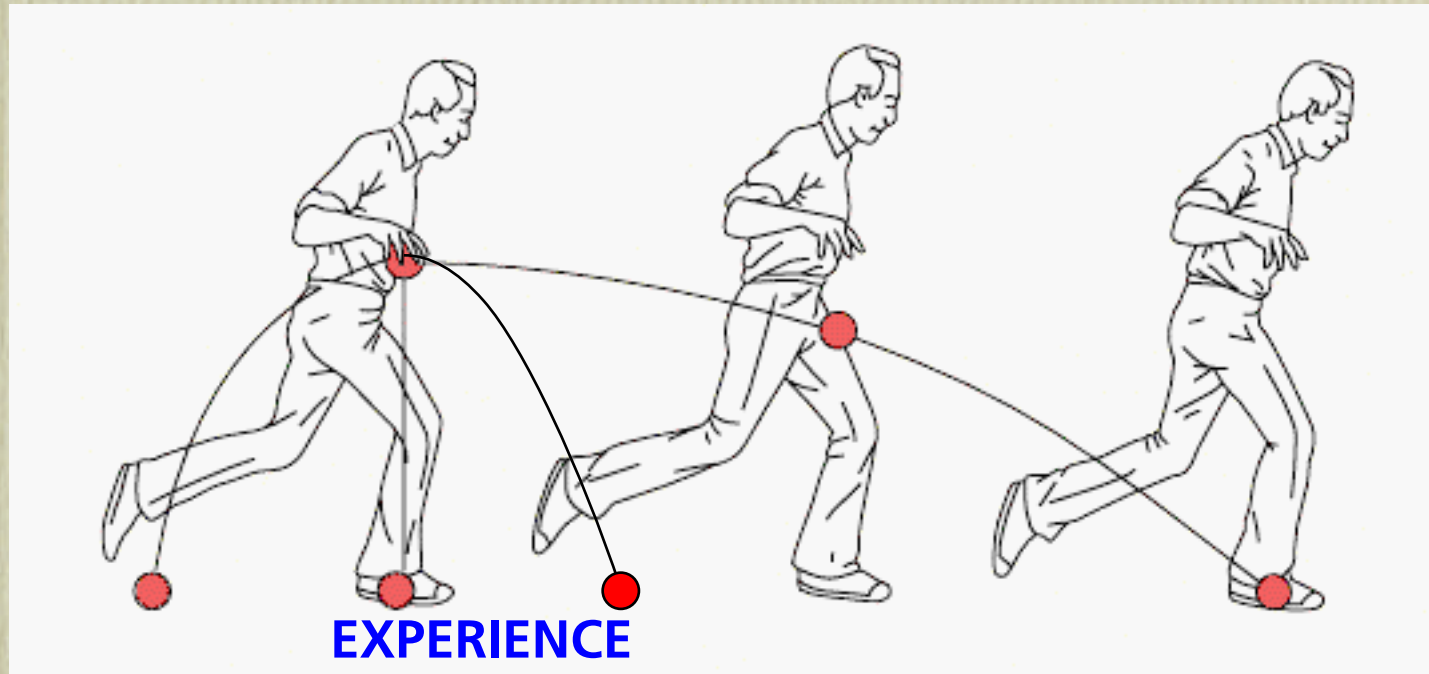


# The lay person





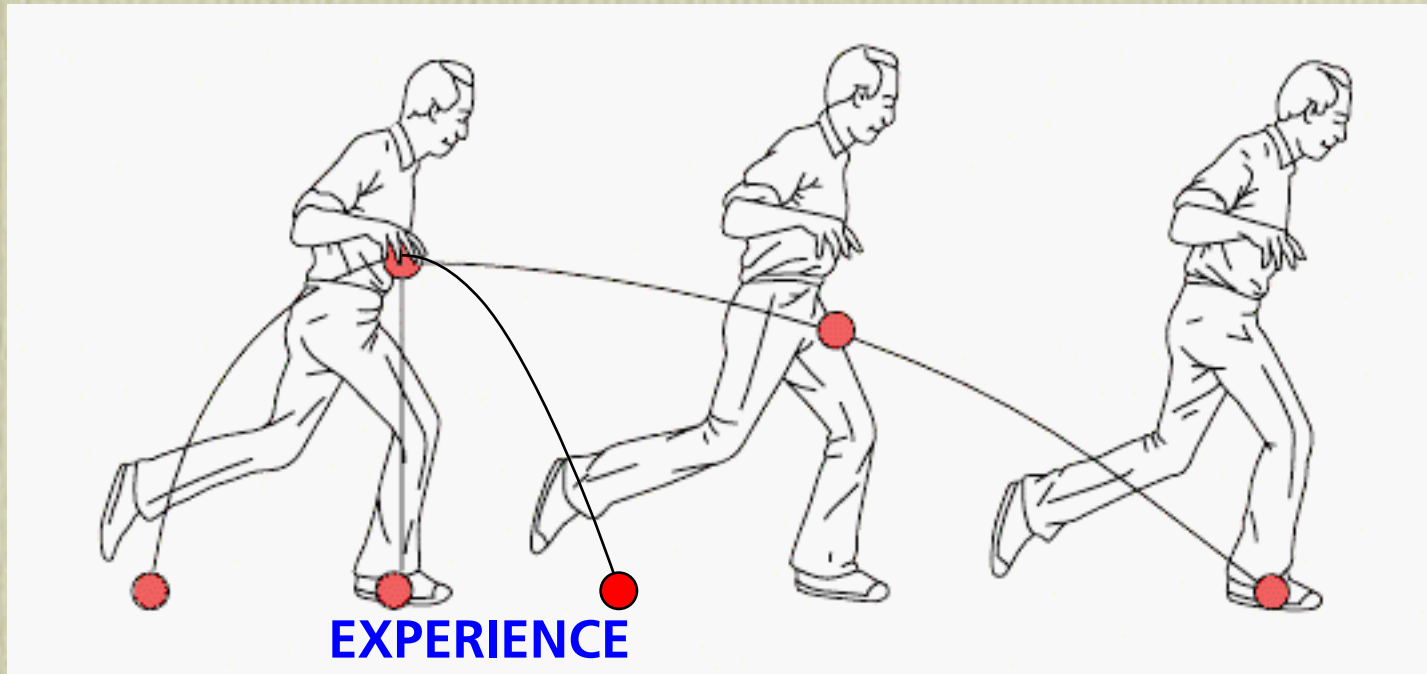
# The lay person



Choice dictated by experience

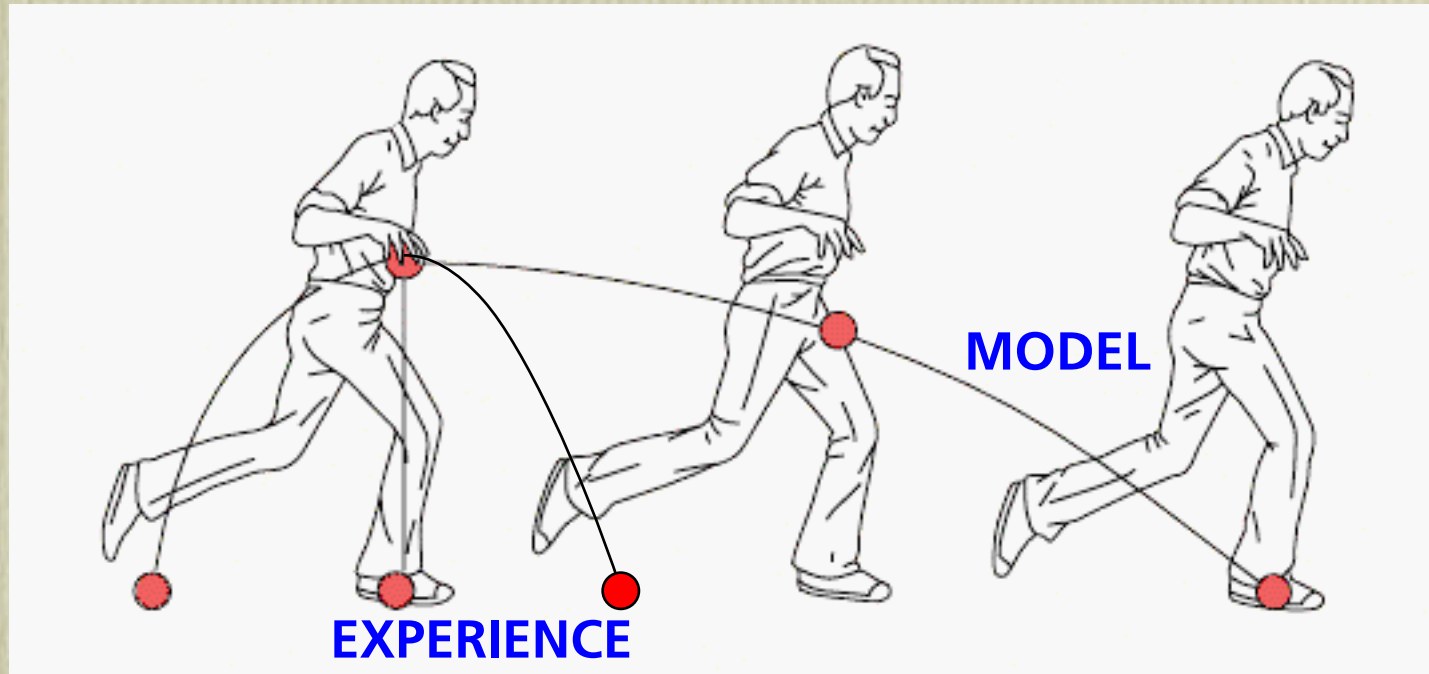


# The physicist





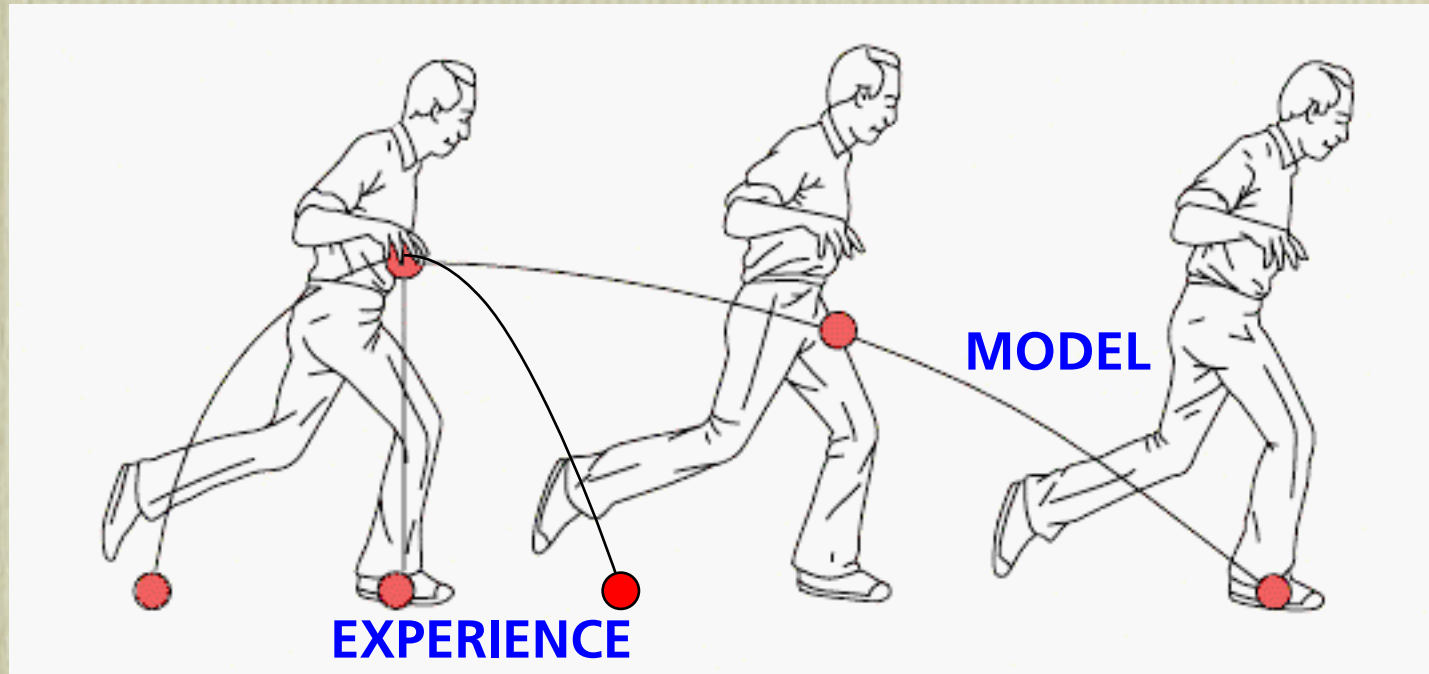
# The physicist



Choice dictated by the model...



# The physicist



...even if representation of model is *wrong*





“Knowing the answer? Or should I stick to my intuition? My intuition *still* tells me that B must be the closest to how it works. But I know perfectly well that path C *must* be the right answer.”



Model overrides experience

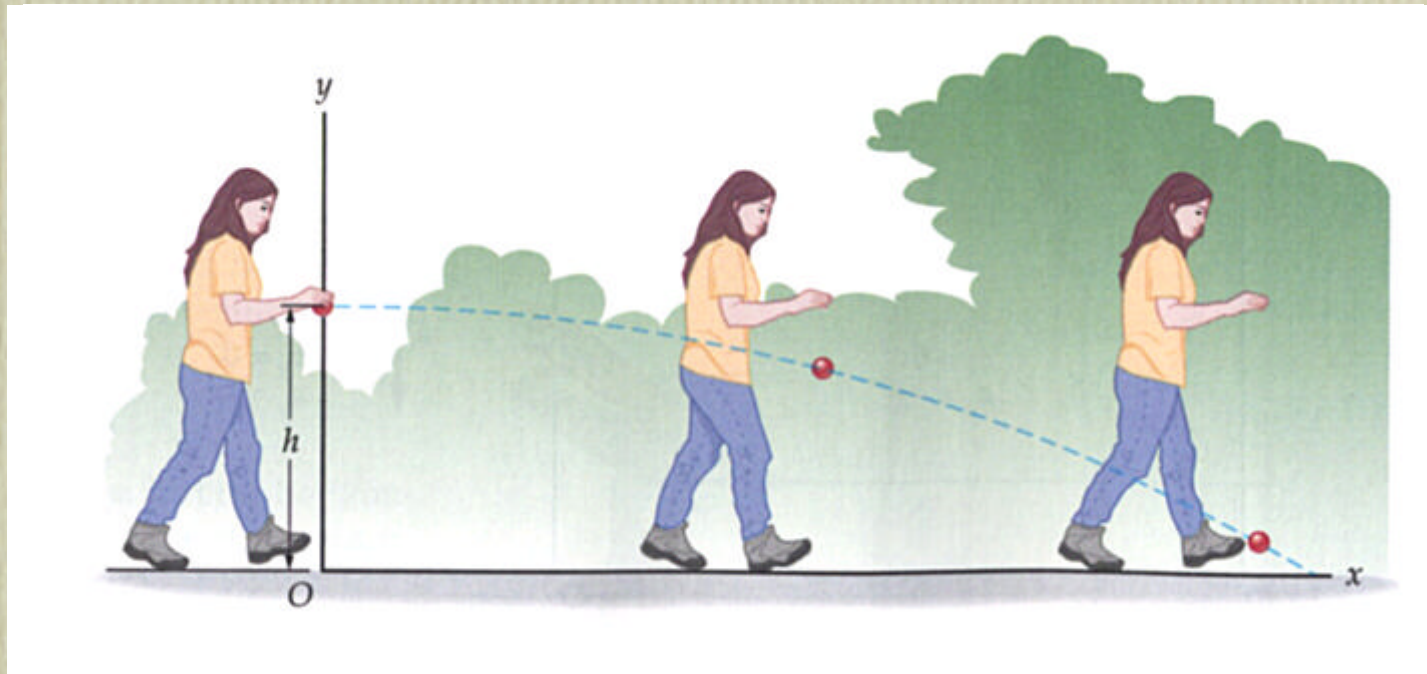




What do our students see?

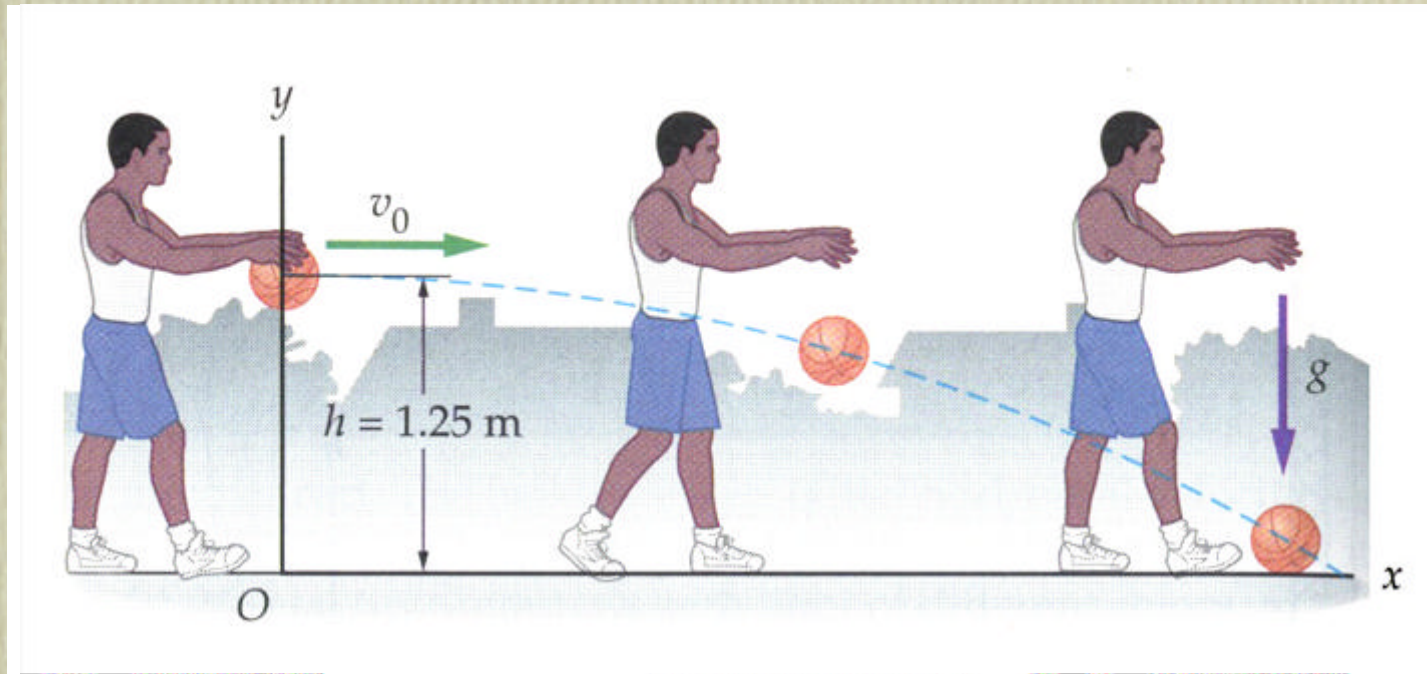


# Microgravity

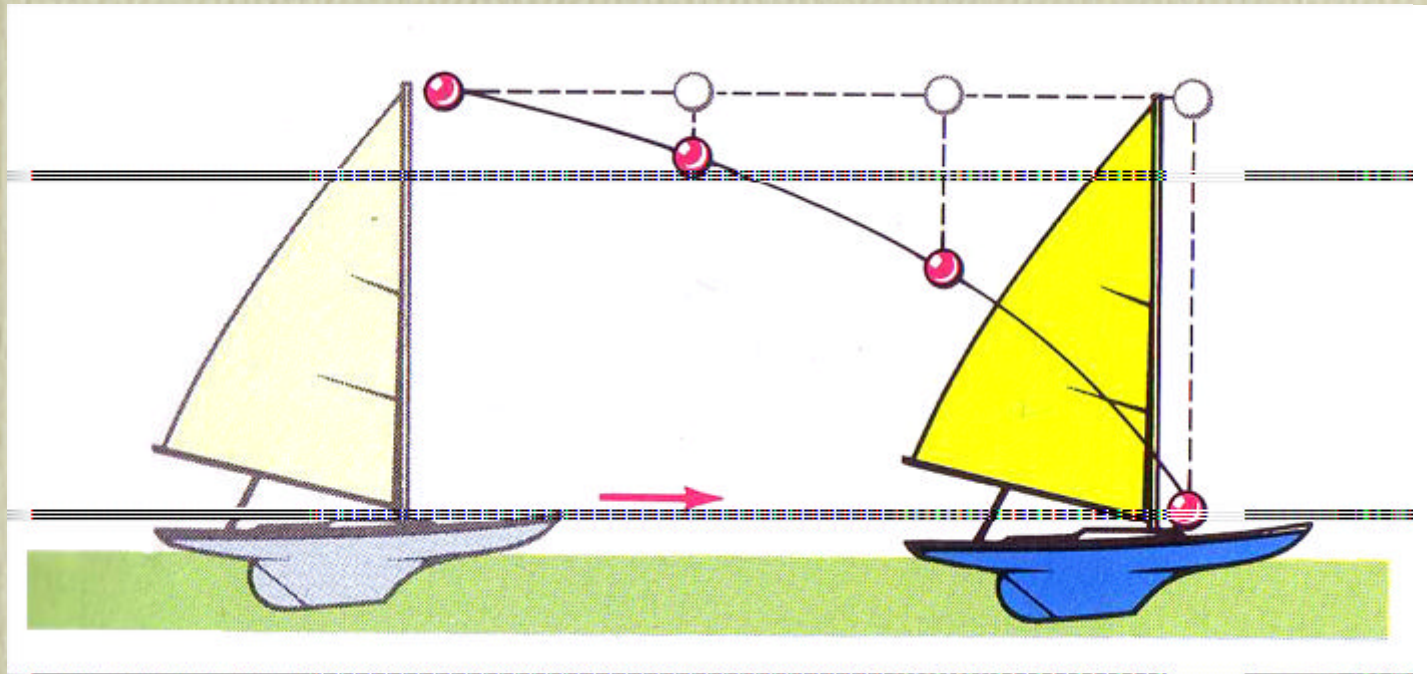




# Microgravity

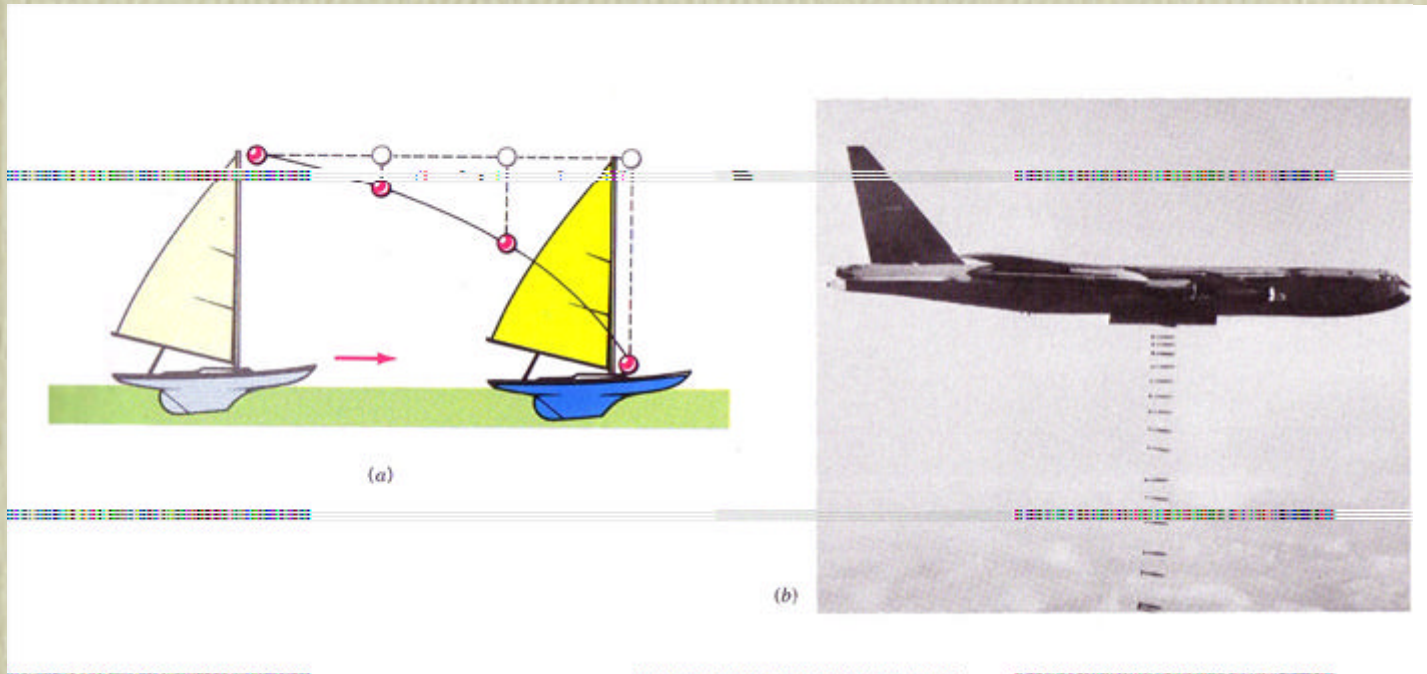


# Microgravity

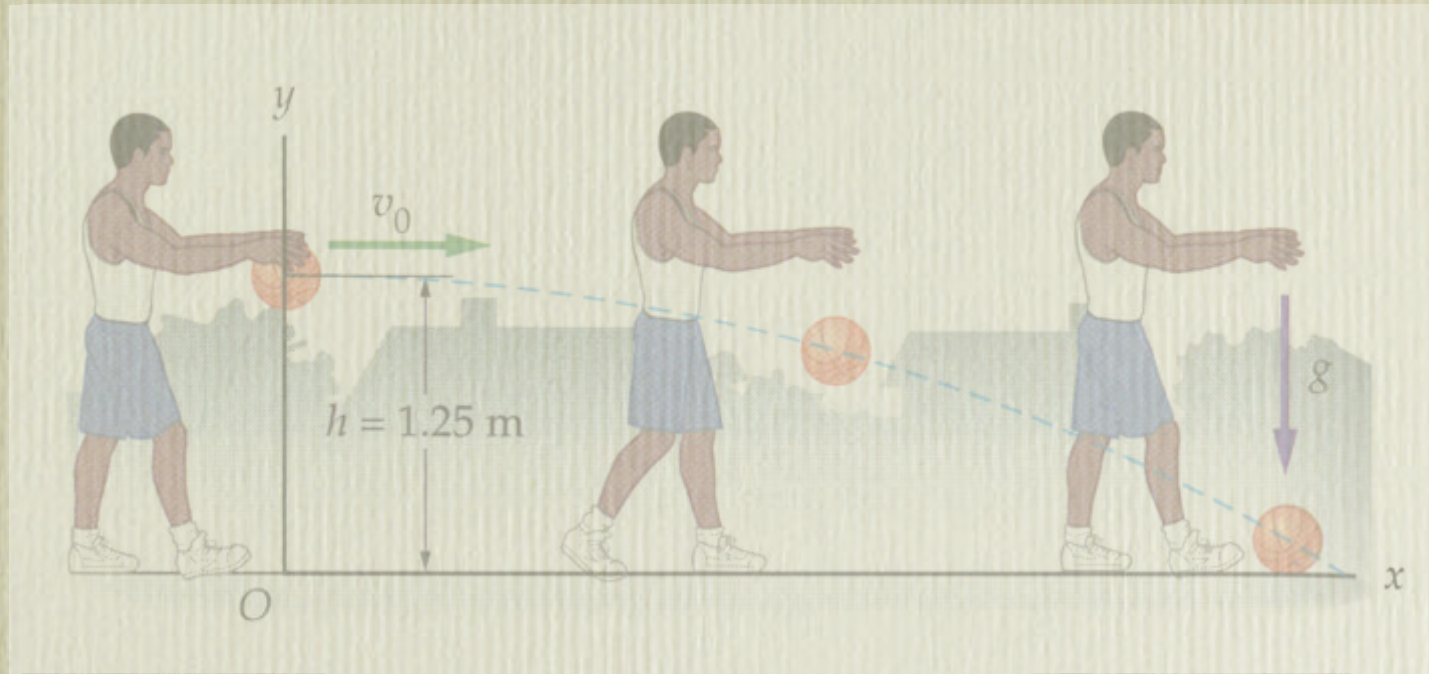




# Microgravity



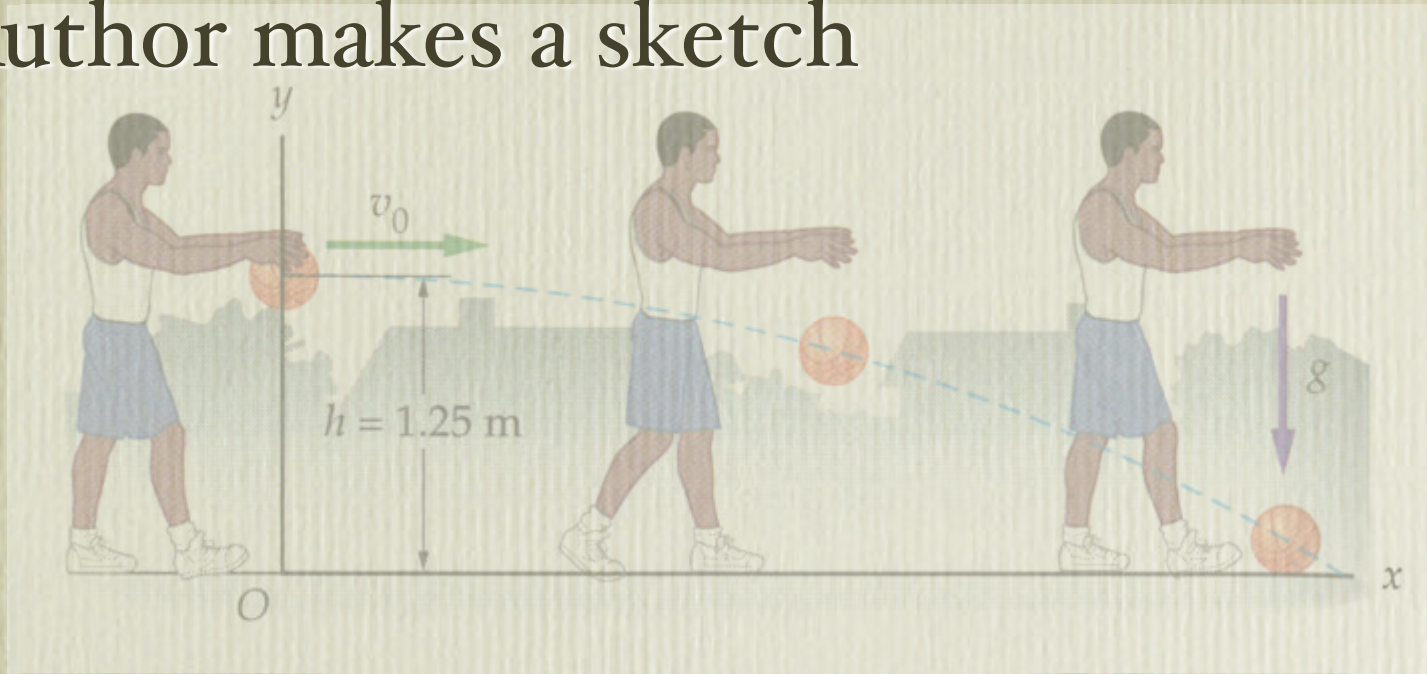
# Microgravity





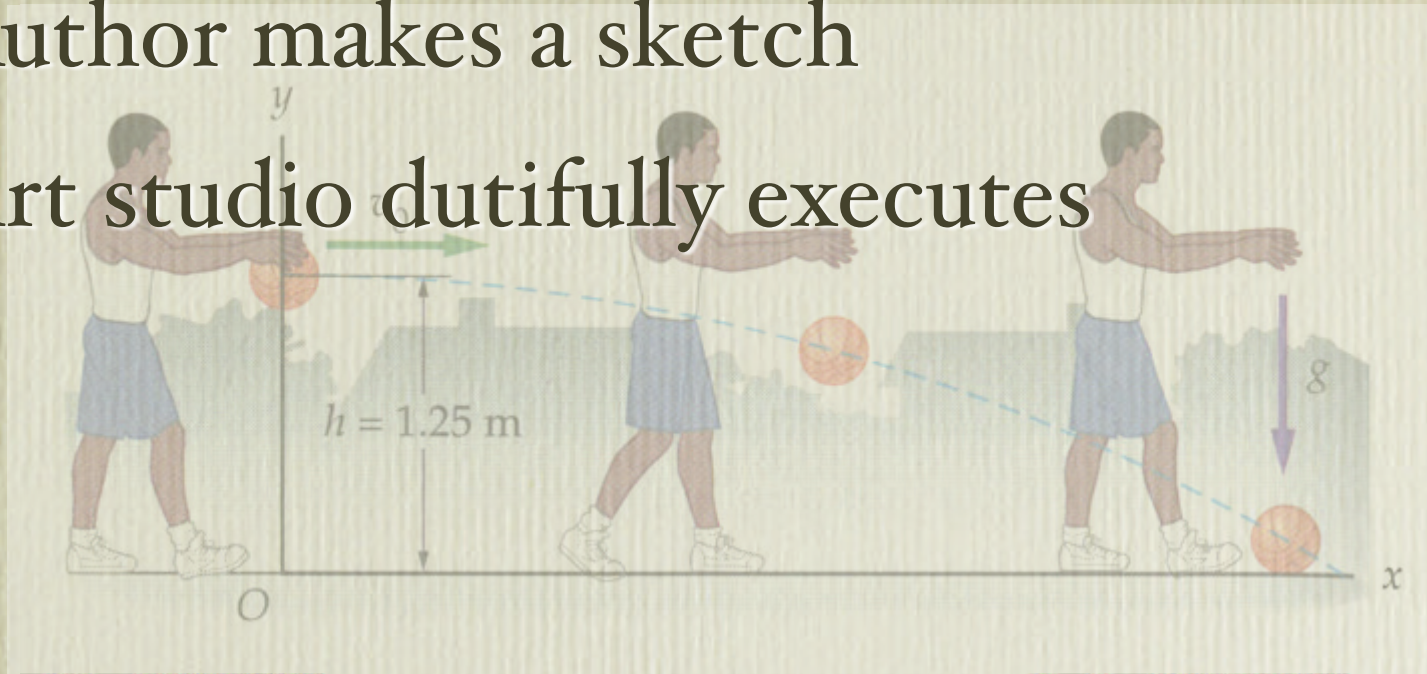
# Microgravity

- Author makes a sketch



# Microgravity

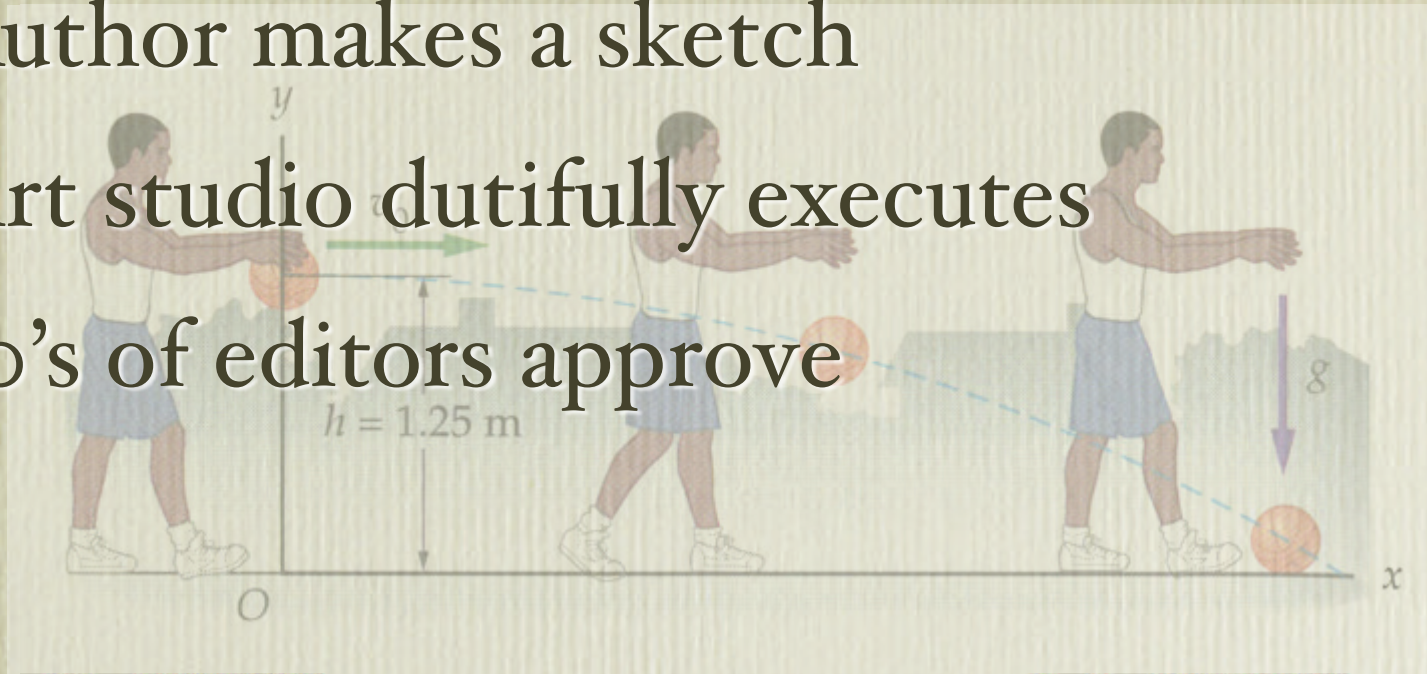
- Author makes a sketch
- Art studio dutifully executes





# Microgravity

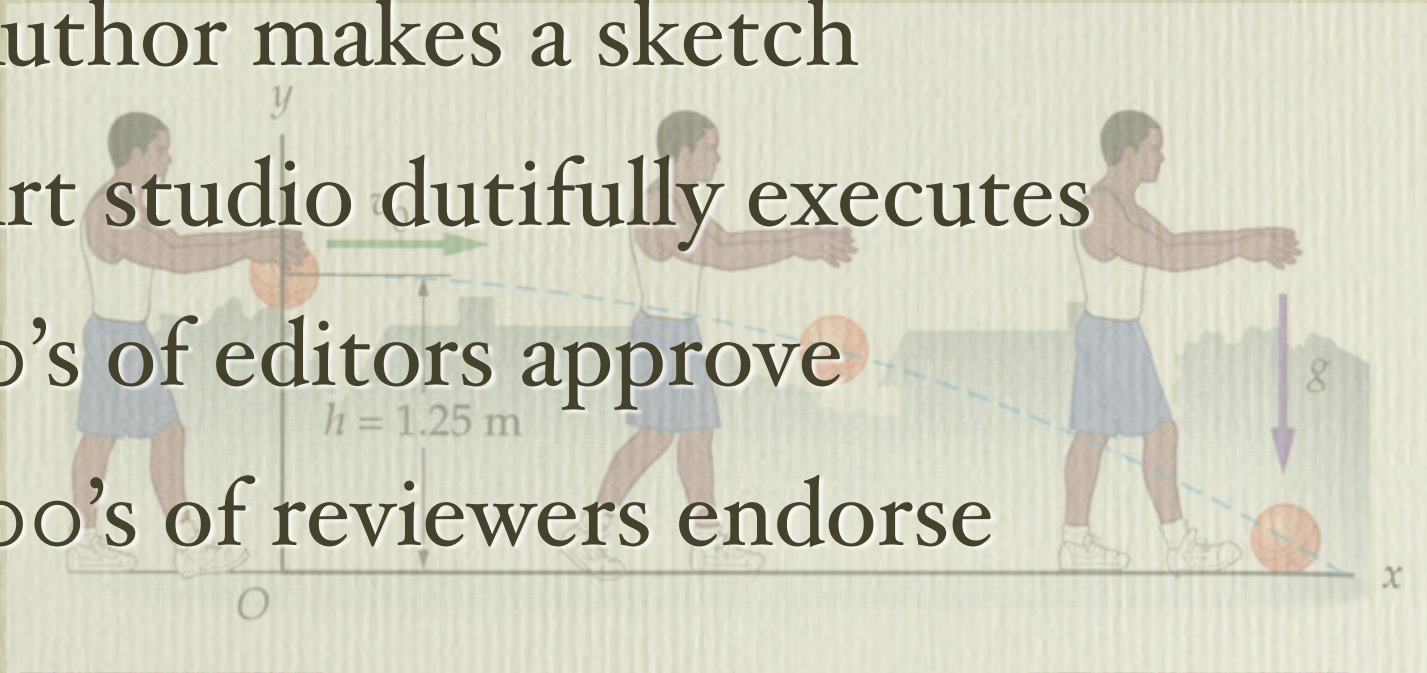
- Author makes a sketch
- Art studio dutifully executes
- 10's of editors approve





# Microgravity

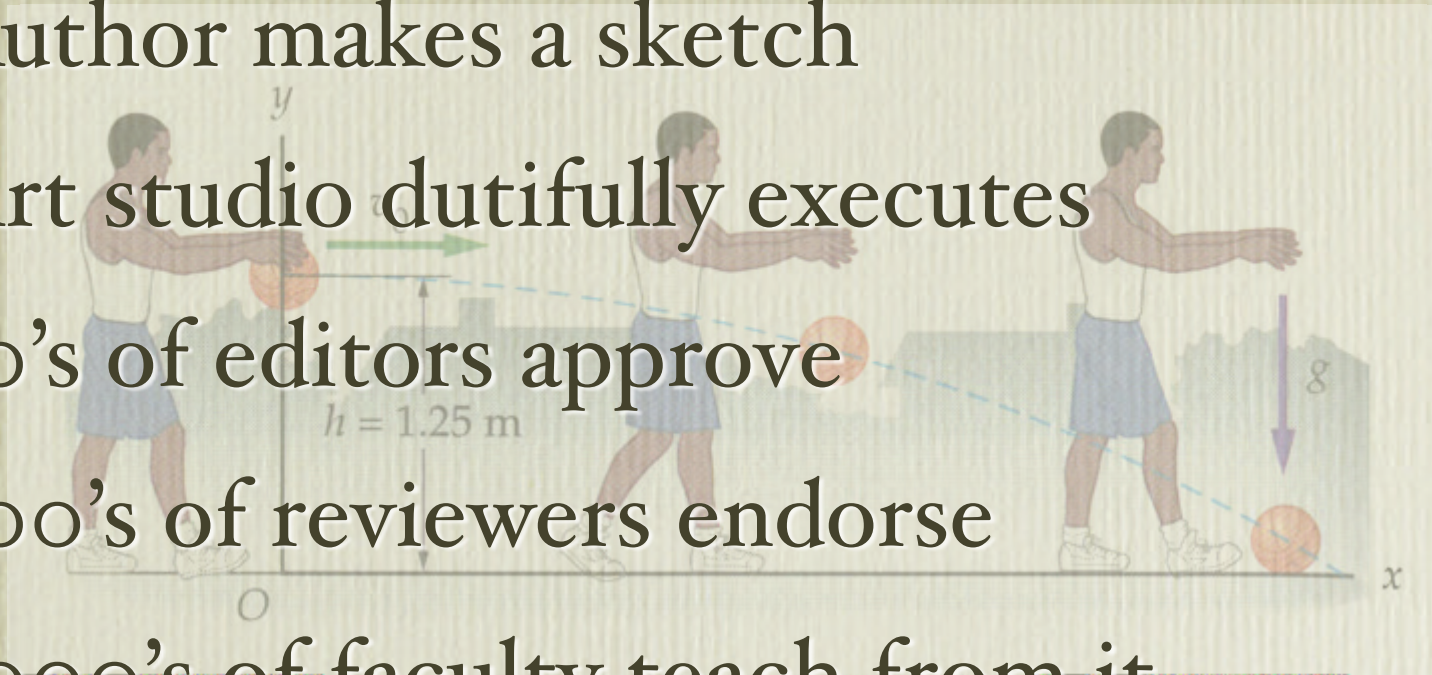
- Author makes a sketch
- Art studio dutifully executes
- 10's of editors approve
- 100's of reviewers endorse





# Microgravity

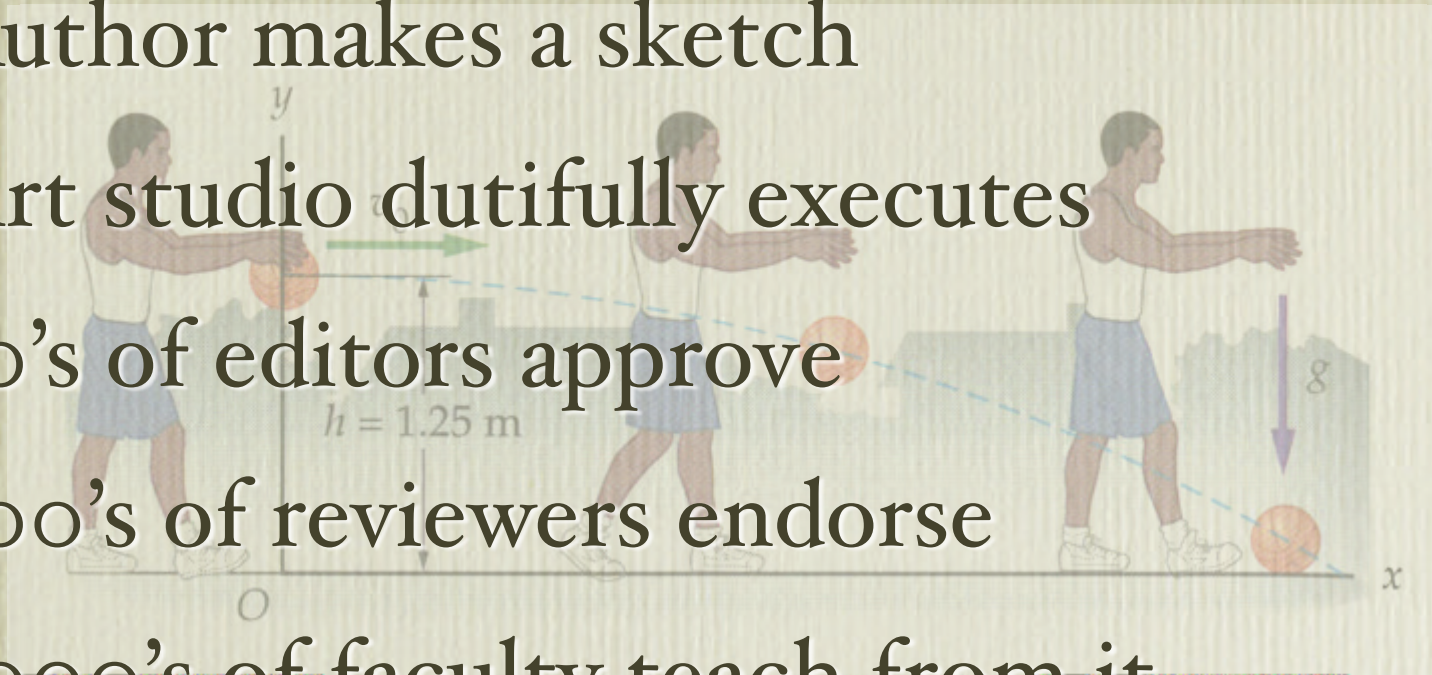
- Author makes a sketch
- Art studio dutifully executes
- 10's of editors approve
- 100's of reviewers endorse
- 1000's of faculty teach from it





# Microgravity

- Author makes a sketch
- Art studio dutifully executes
- 10's of editors approve
- 100's of reviewers endorse
- 1000's of faculty teach from it
- 10,000's of students grudgingly regurgitate



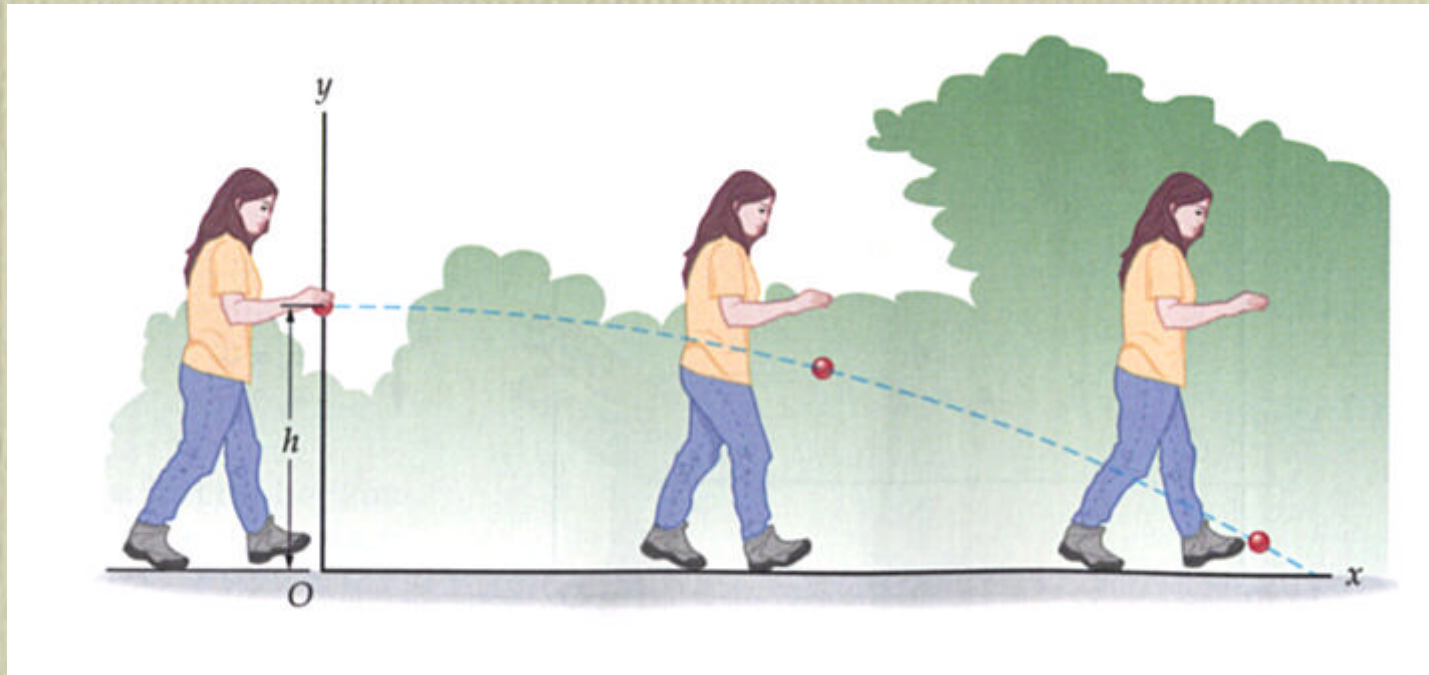


Physics is...

“almost on a totally different plane of existence.”

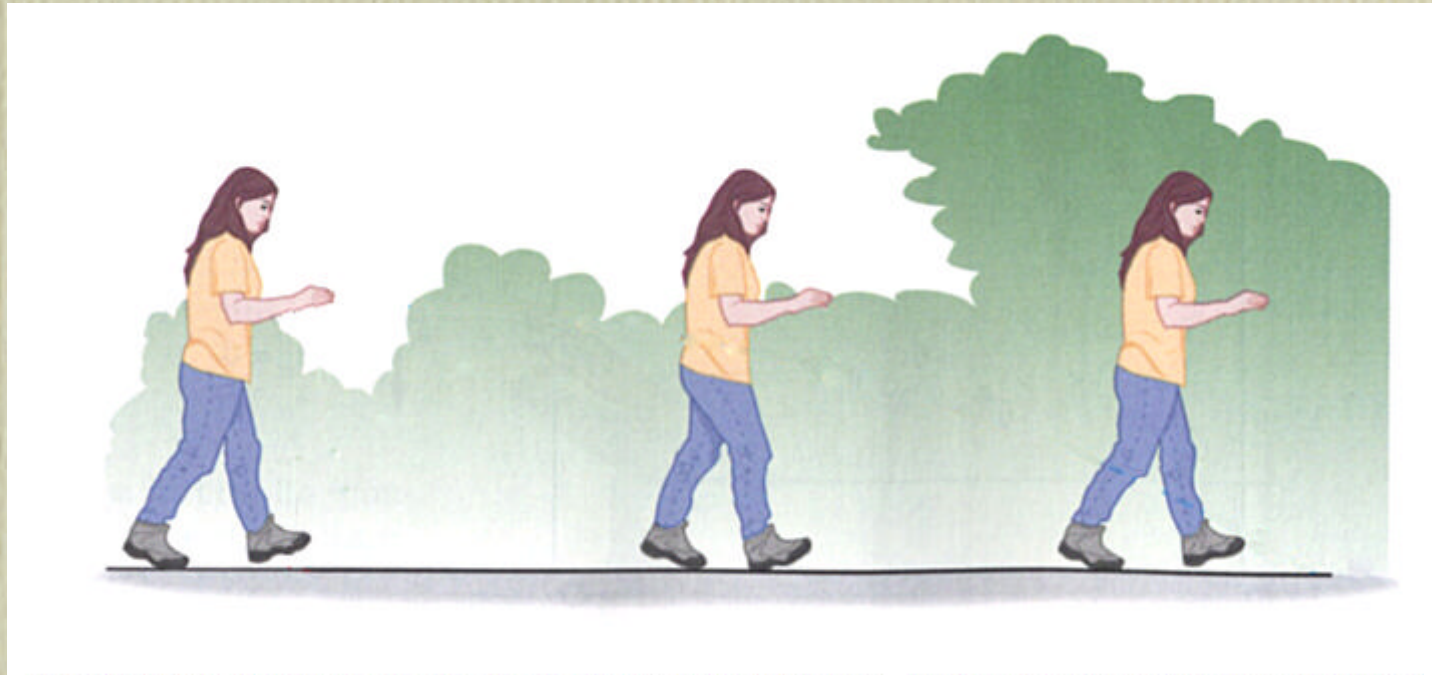


# Realism





# Realism

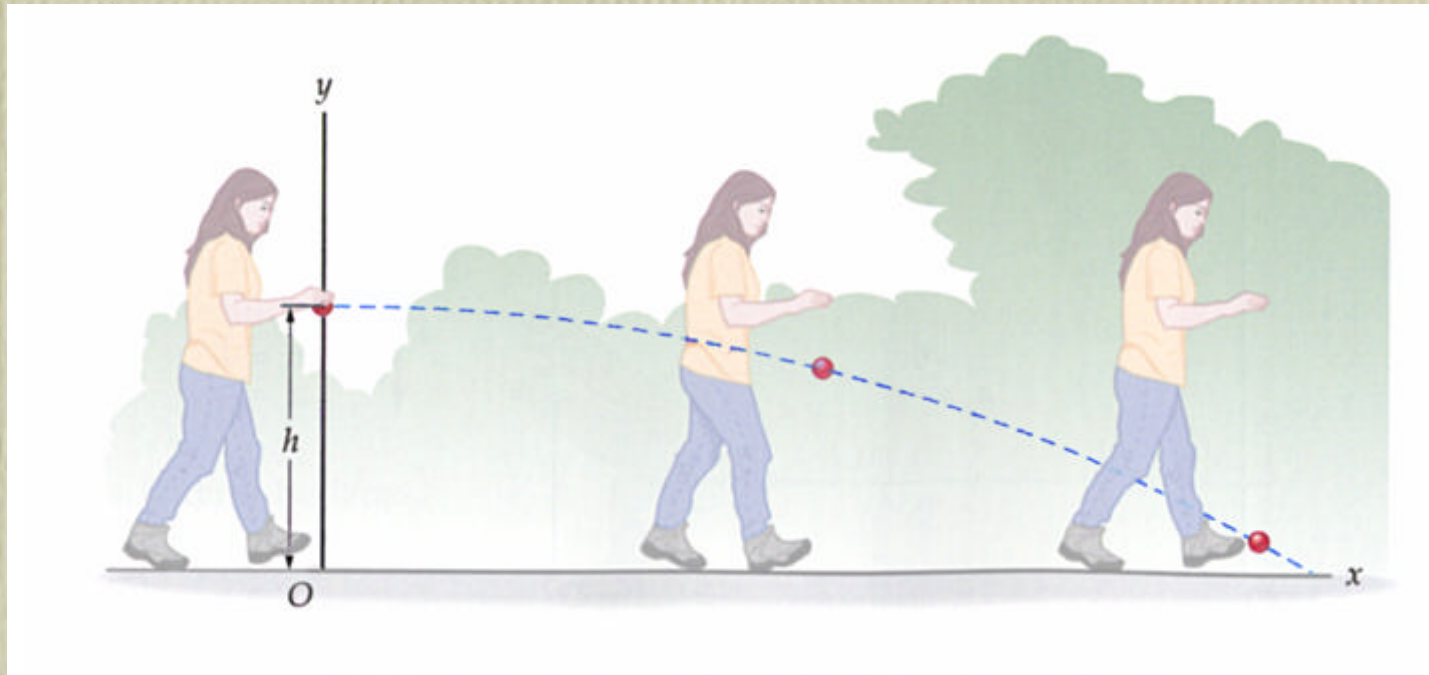


# Realism

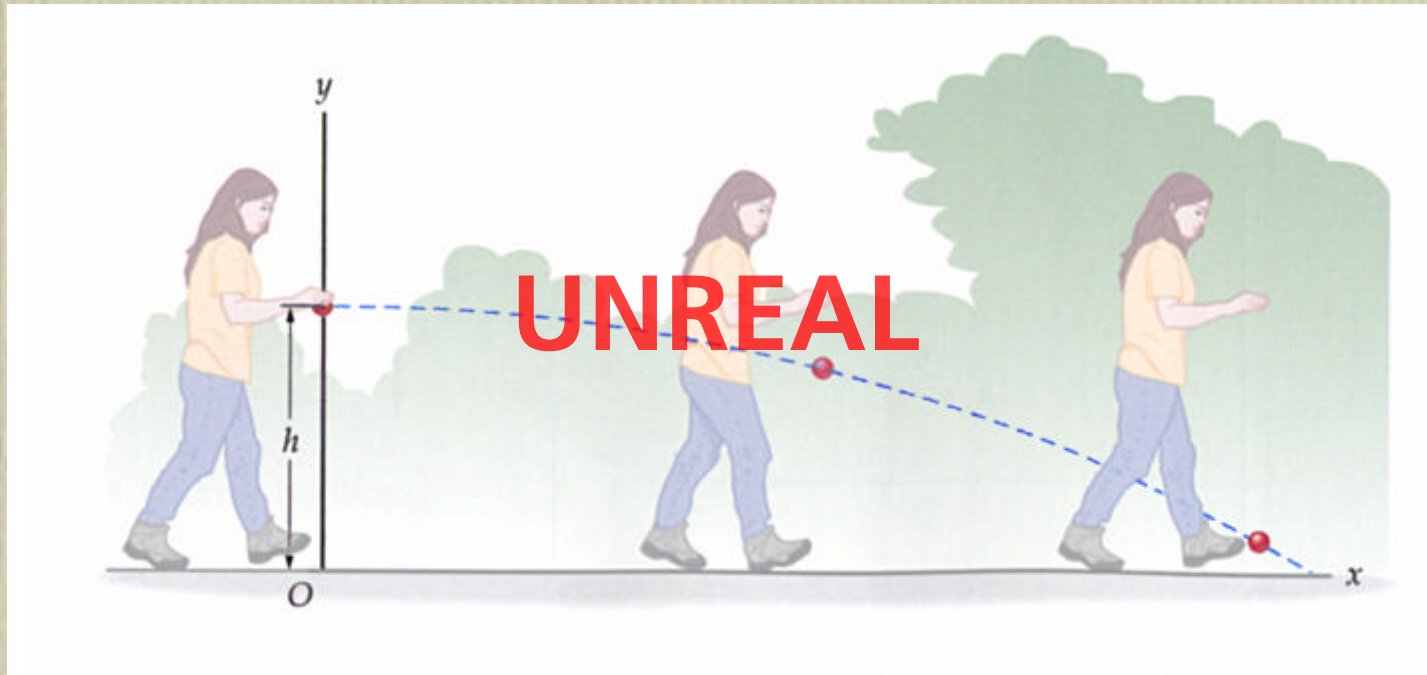




# Realism

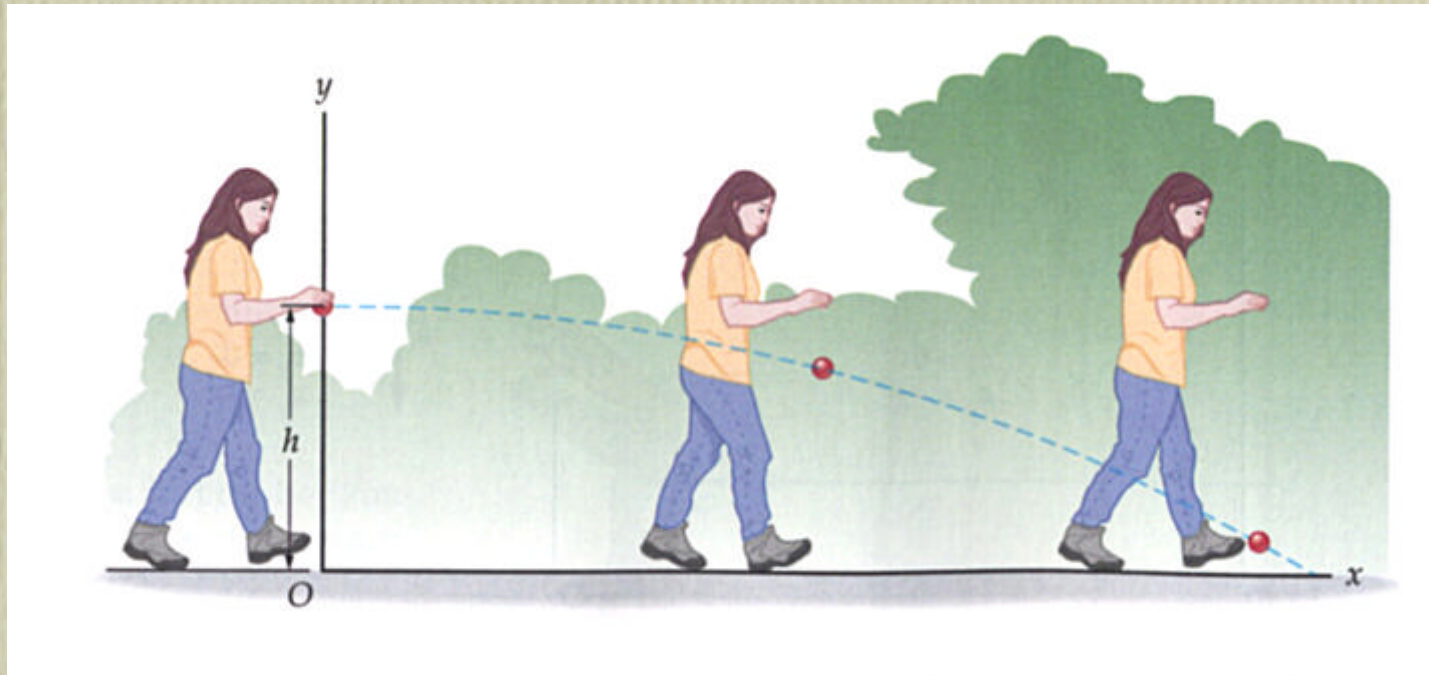


# Realism





# Realism



background:

realistic

physics:

unrealistic



What do people look at?

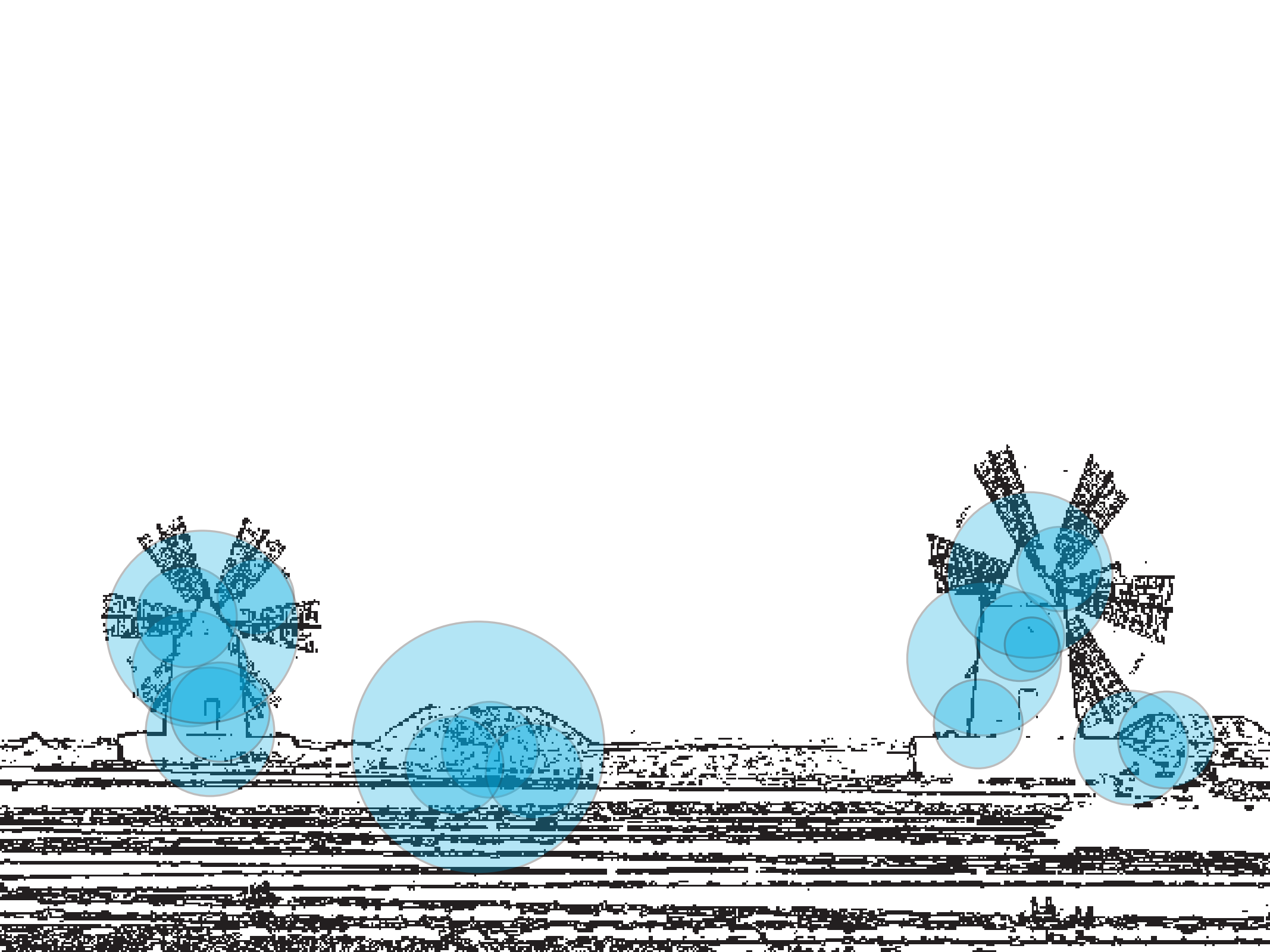






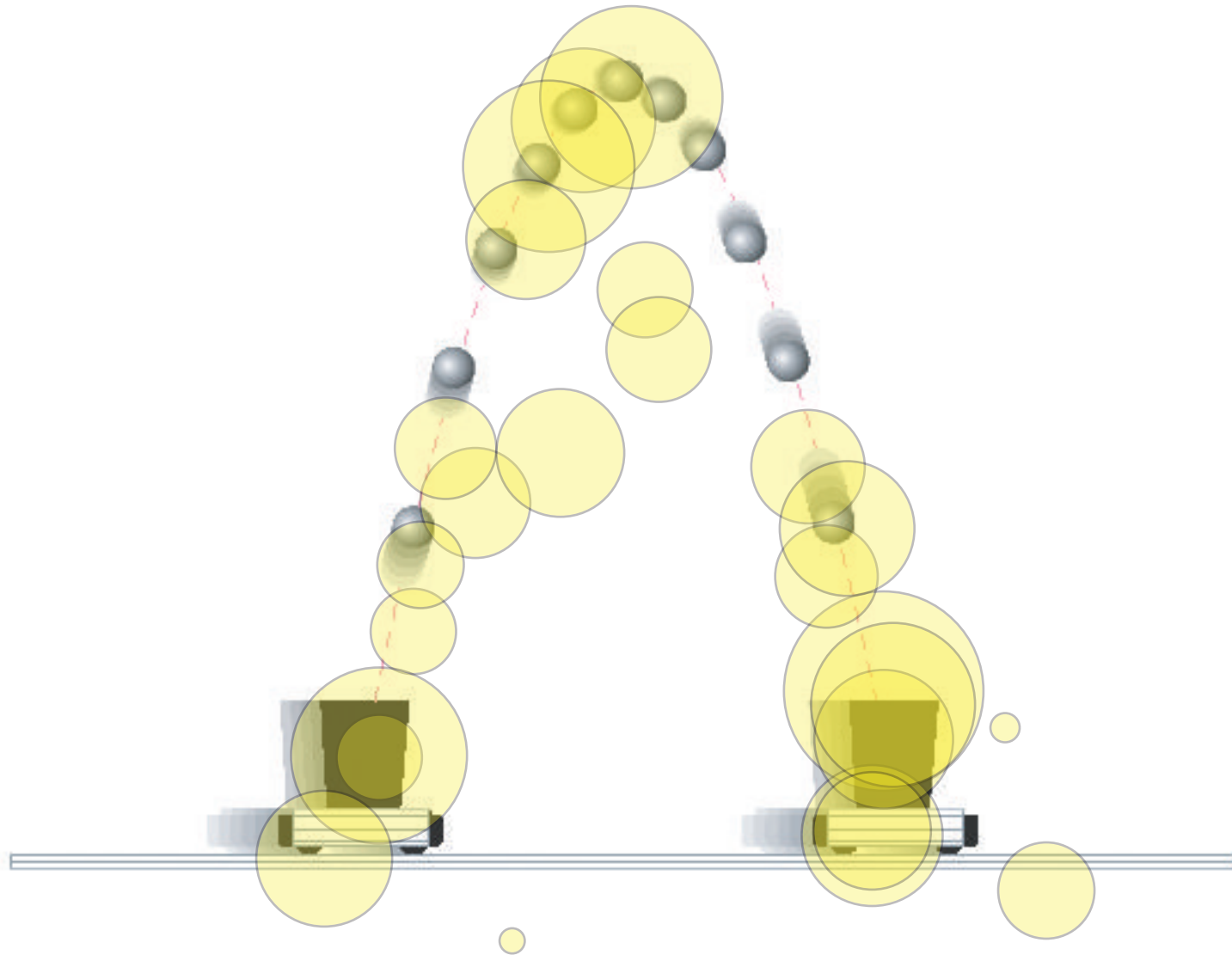










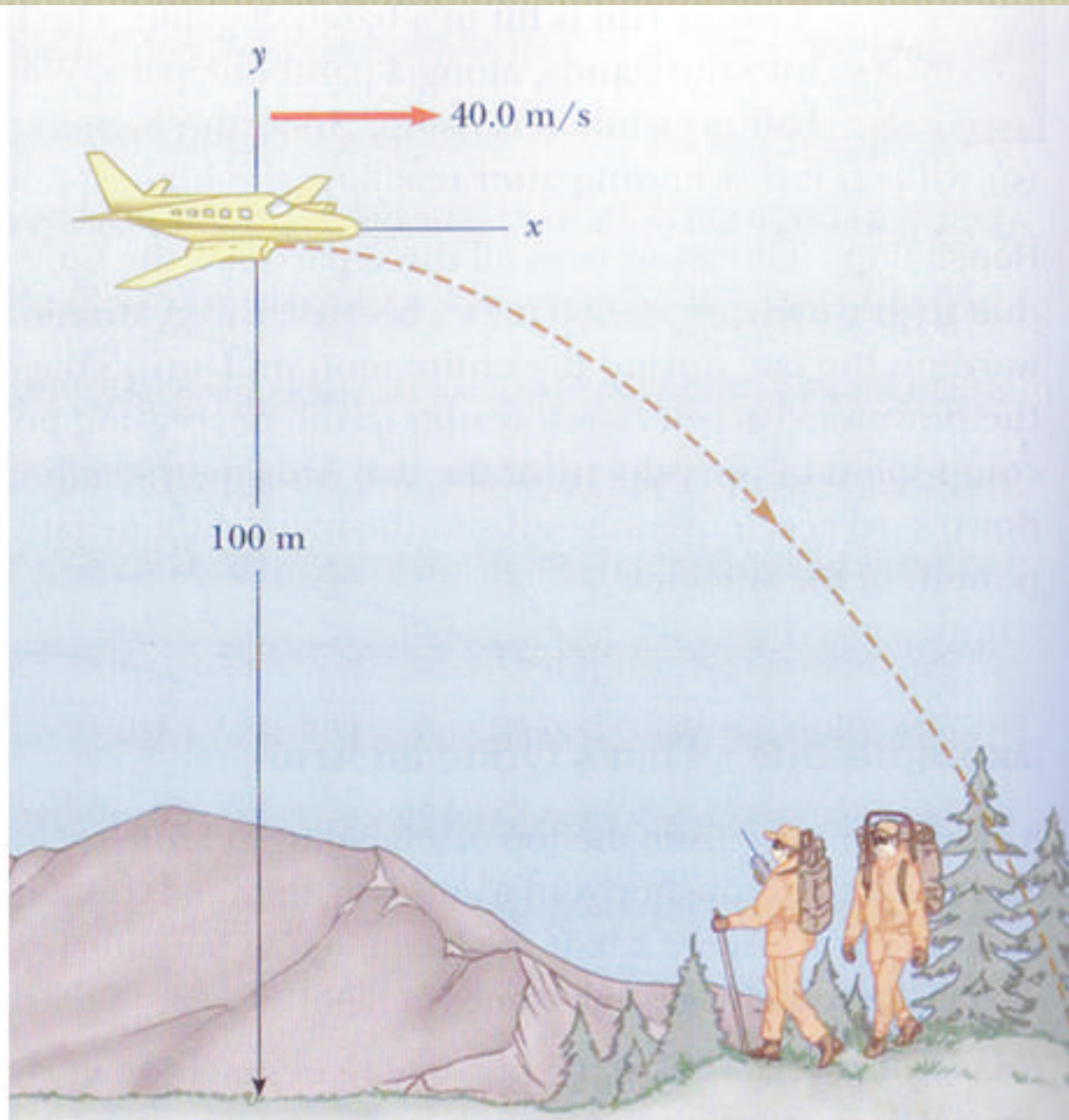


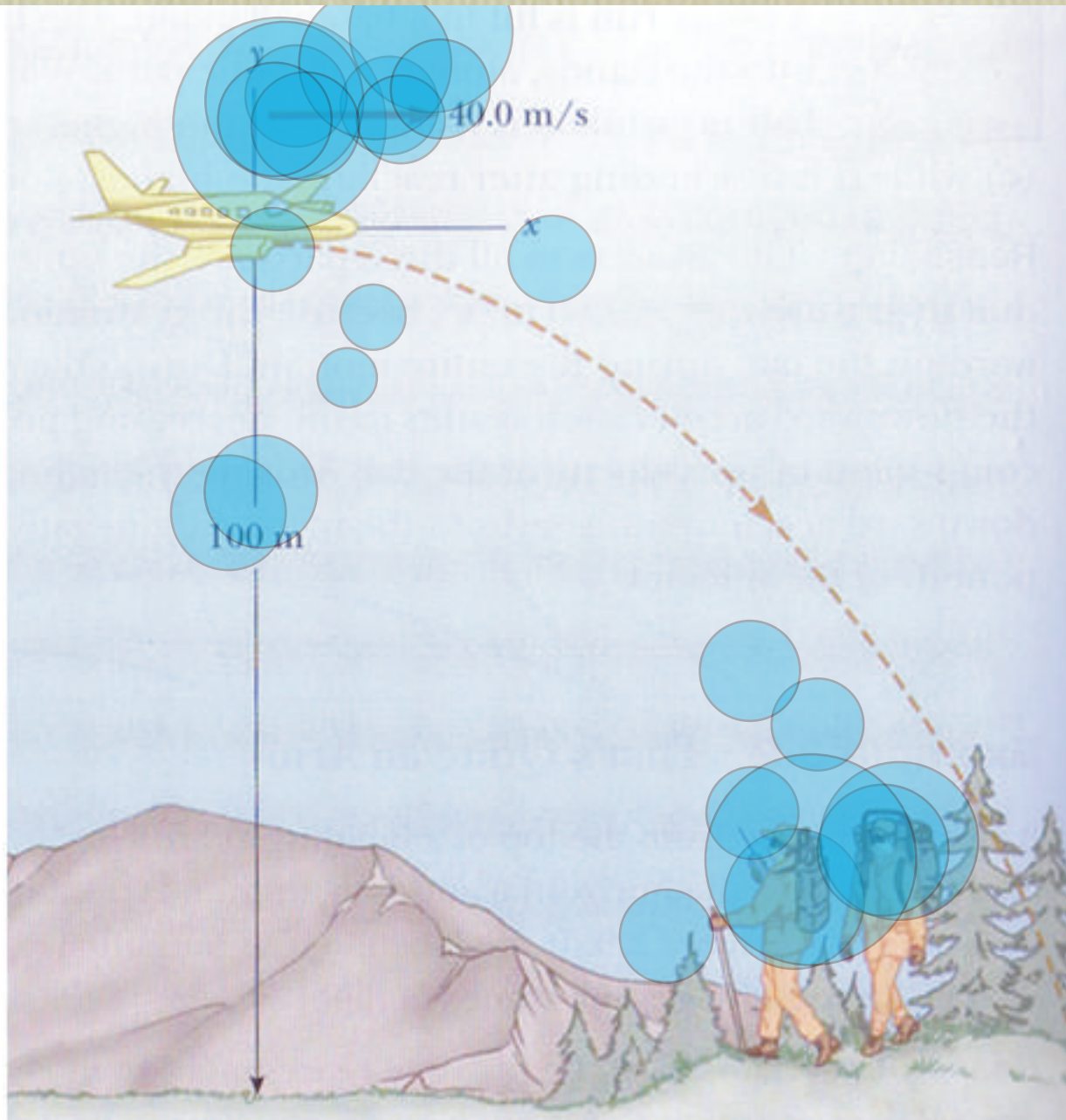
# People look at

- Parabolic motion of ball
- Carts

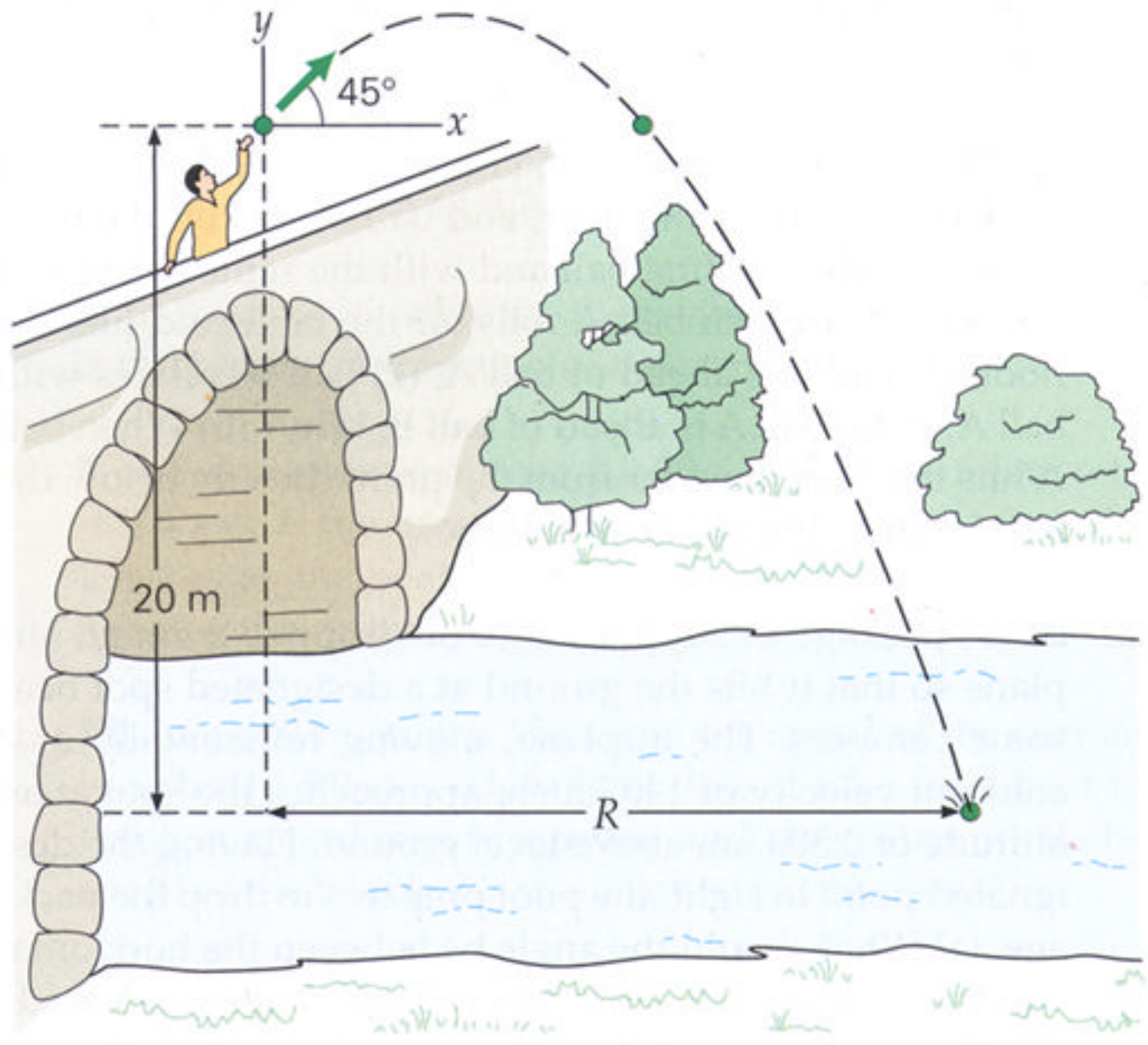


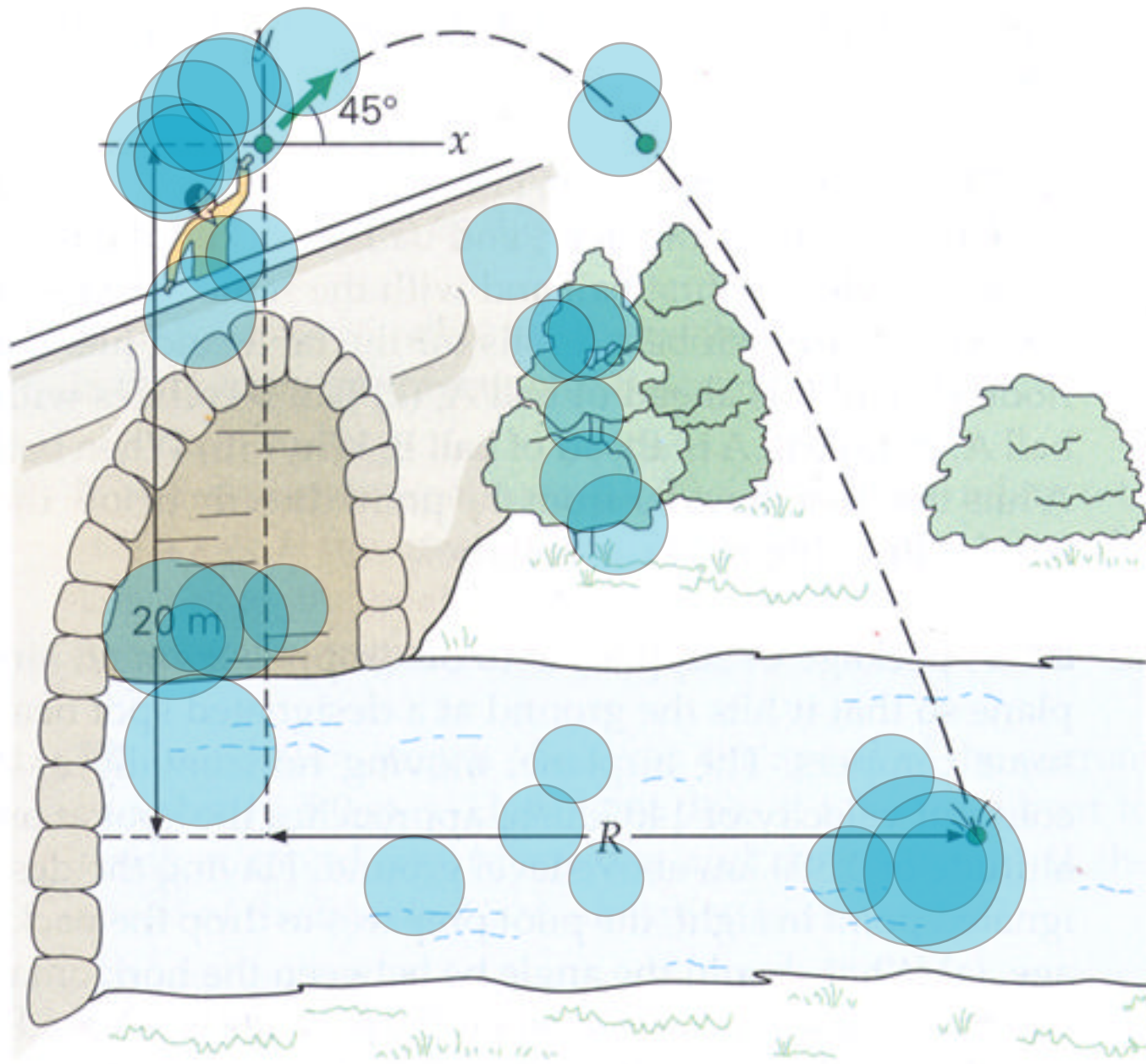




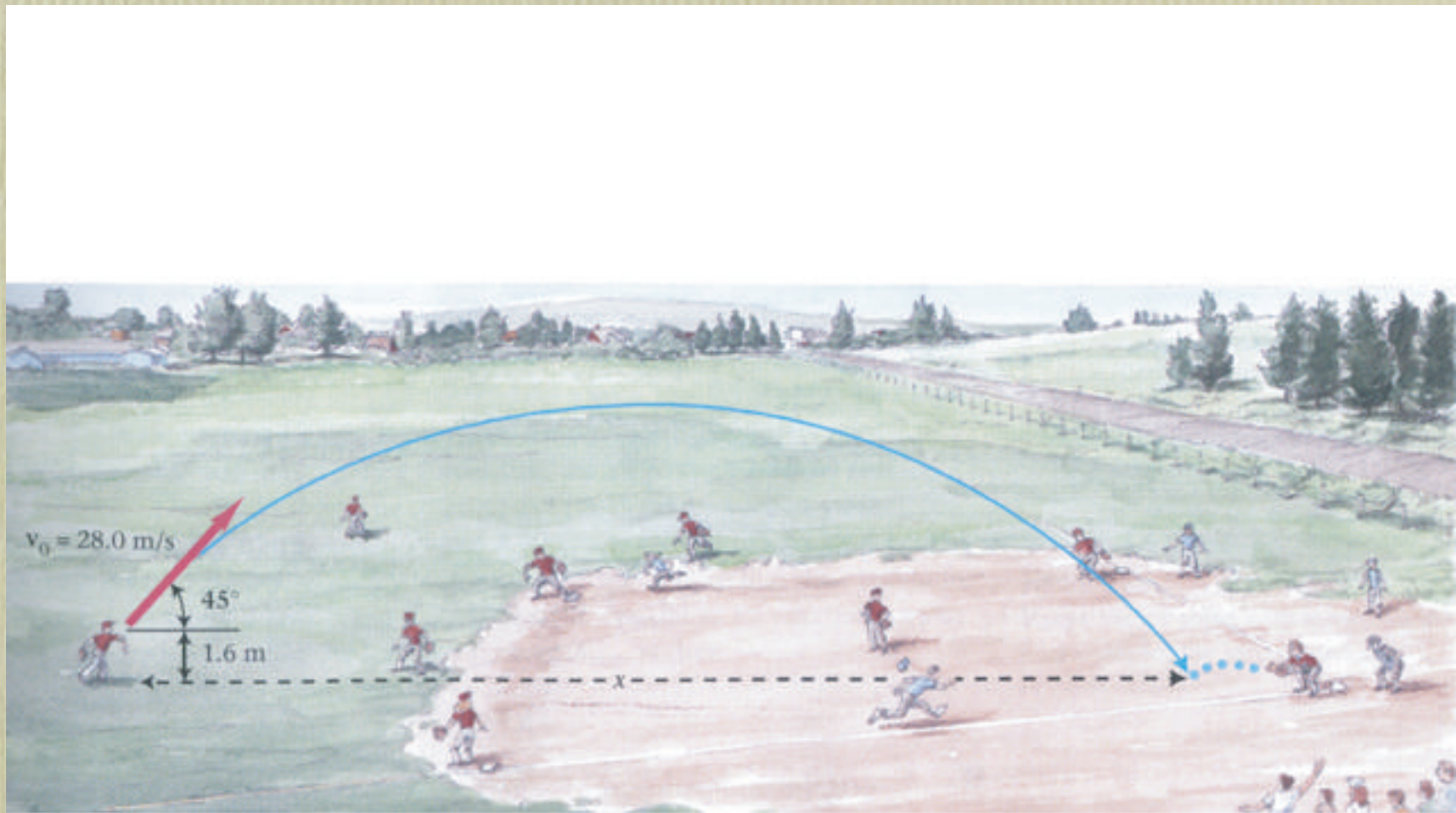


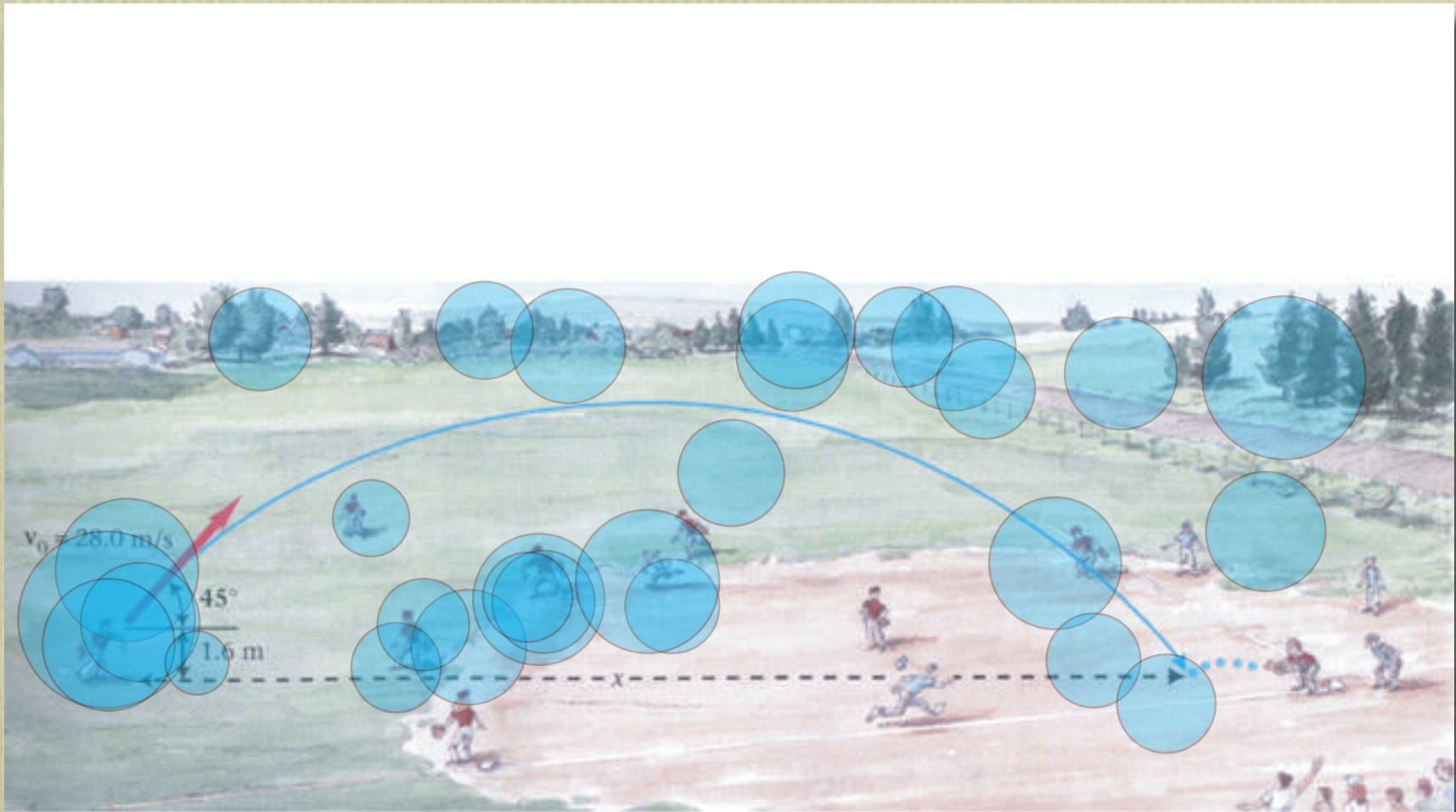




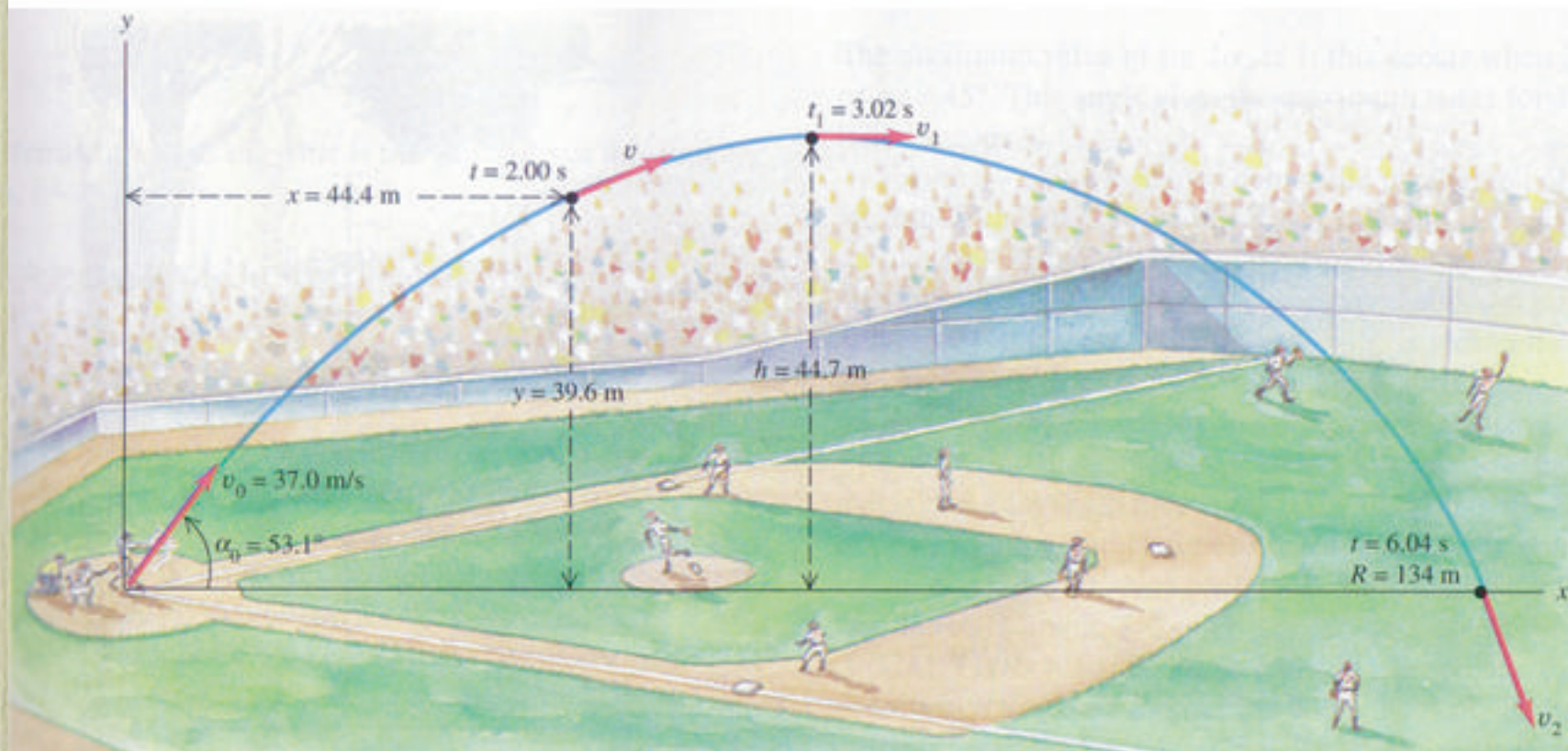


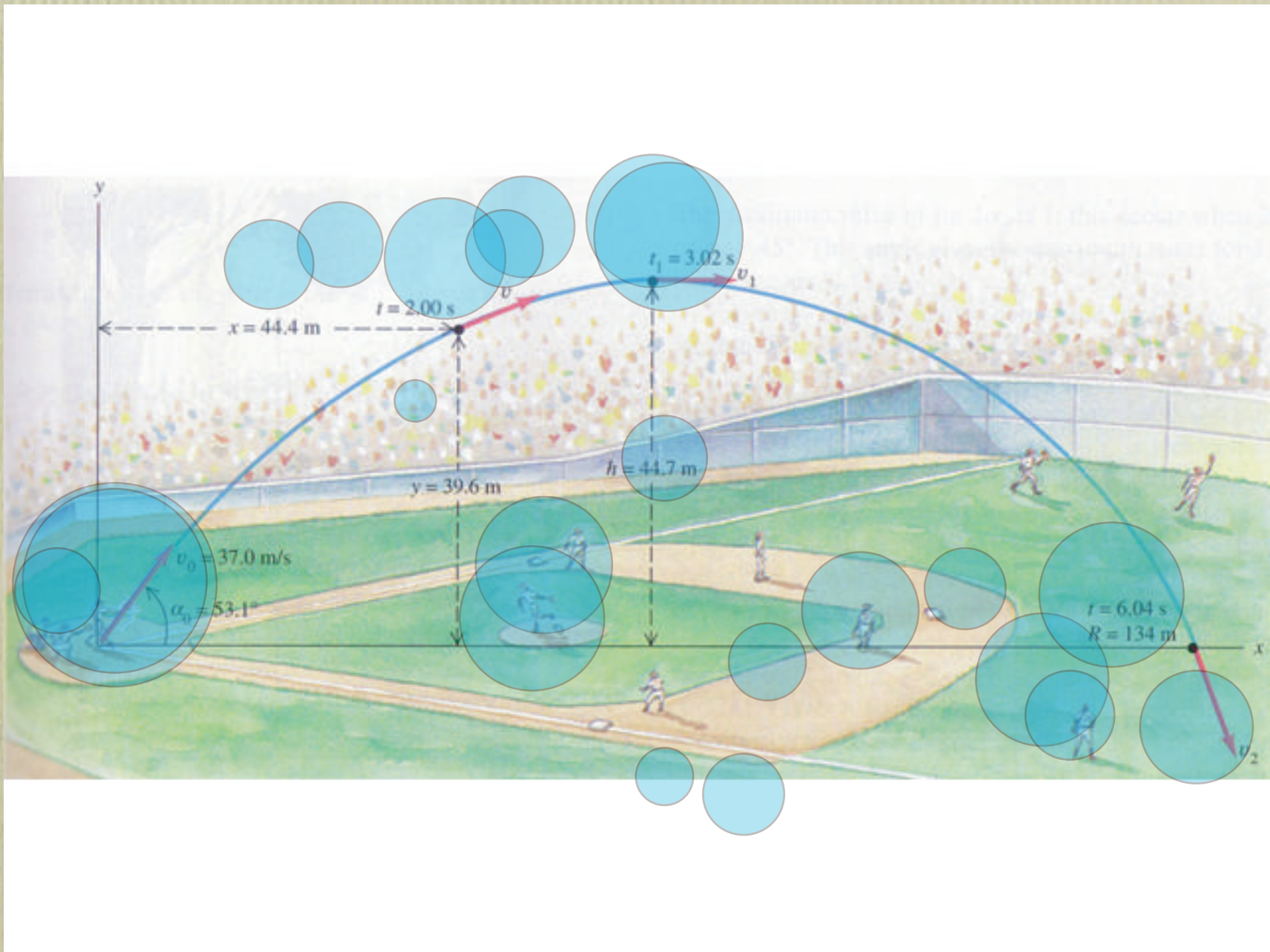














# People look at

- People
- Text labels
- Other (distracting) elements



# People look at

- People
- Text labels
- Other (distracting) elements

but not the parabolic motion!





Misplaced realism disconnects  
physics from the real world







# The confusing world of physics



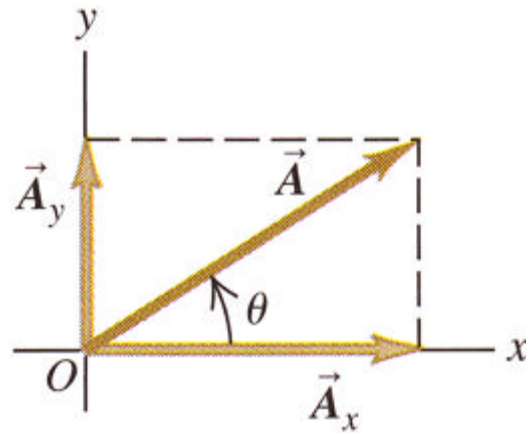


Are vector components vectors?



# Yes

18



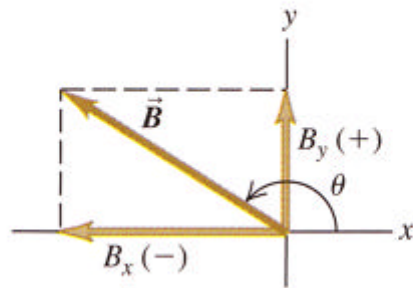
**1.13** Vectors  $\vec{A}_x$  and  $\vec{A}_y$  are the rectangular component vectors of  $\vec{A}$  in the directions of the x- and y-axes. For the vector  $\vec{A}$  shown here, the components  $A_x$  and  $A_y$  are both positive.



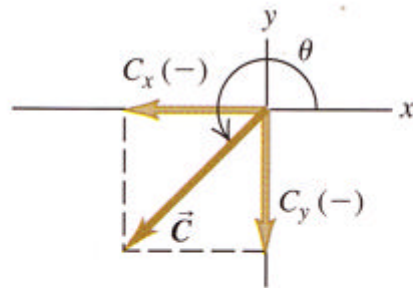


# No

19



(a)



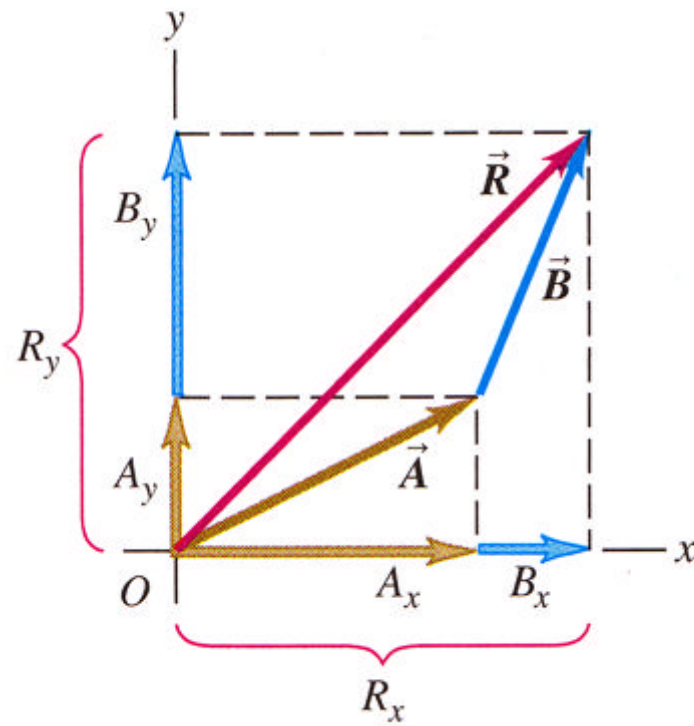
(b)

**1.14** The components of a vector may be positive or negative numbers.



# No

21



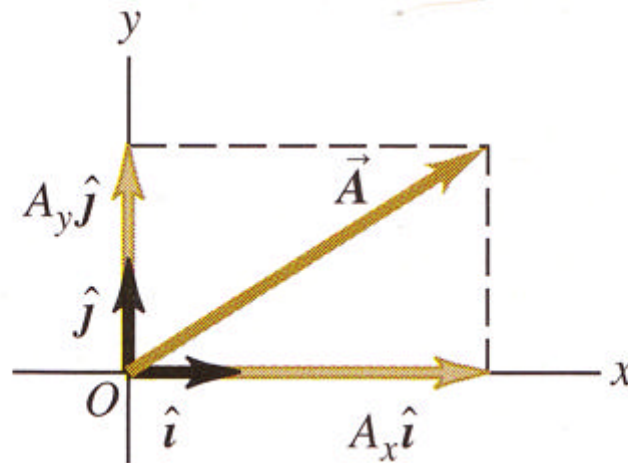


Are vector components vectors?  
*Yes* on even pages, *no* on odd ones



# Wait a minute...

23



**1.18** Using unit vectors, we can express a vector  $\vec{A}$  in terms of its components  $A_x$  and  $A_y$  as  $\vec{A} = A_x \hat{i} + A_y \hat{j}$ .



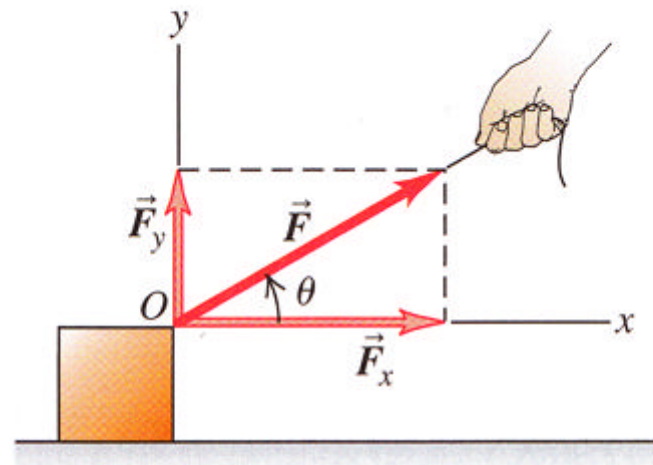


What about forces?



# Yes

121



Component vectors:  $\vec{F}_x$  and  $\vec{F}_y$   
Components:  $F_x = F \cos \theta$  and  $F_y = F \sin \theta$

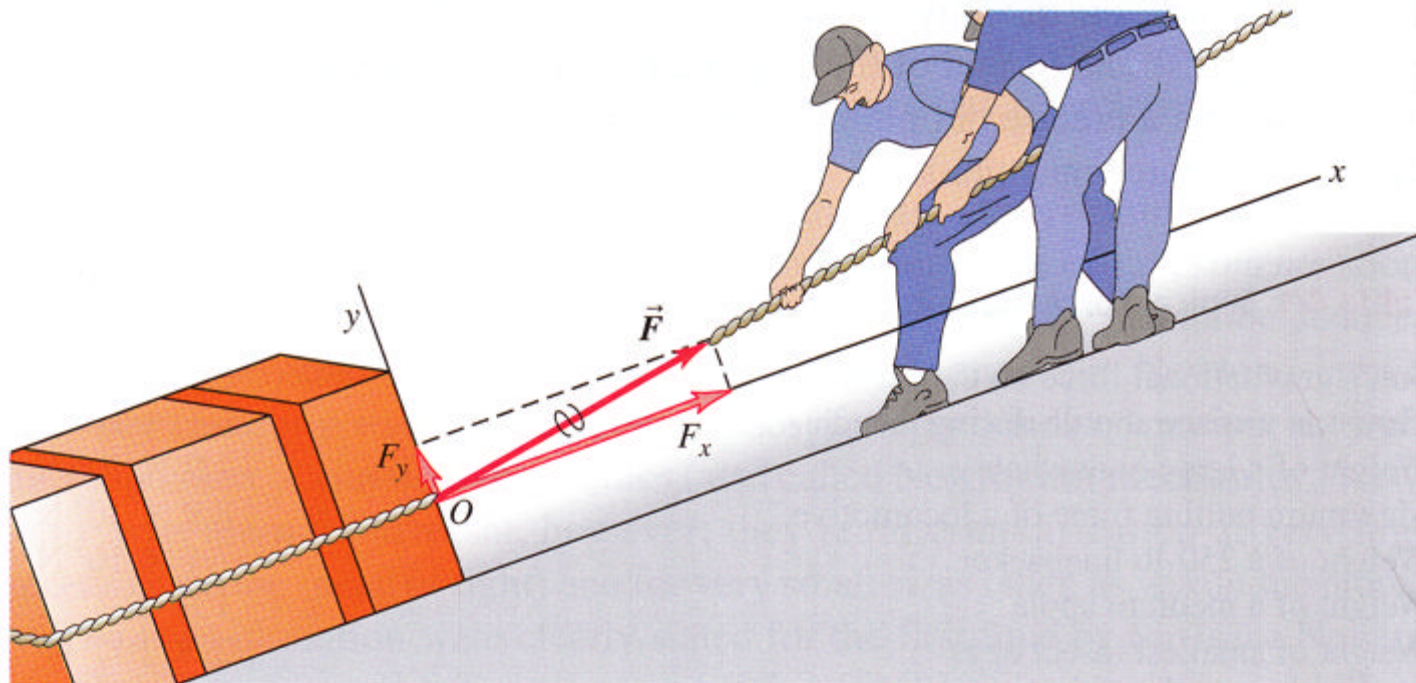
**4.3** The force  $\vec{F}$ , which acts at an angle  $\theta$  from the  $x$ -axis, may be replaced by its rectangular component vectors  $\vec{F}_x$  and  $\vec{F}_y$ .





# No

122



**4.4**  $F_x$  and  $F_y$  are the components of  $\vec{F}$  parallel and perpendicular to the sloping surface of the inclined plane.



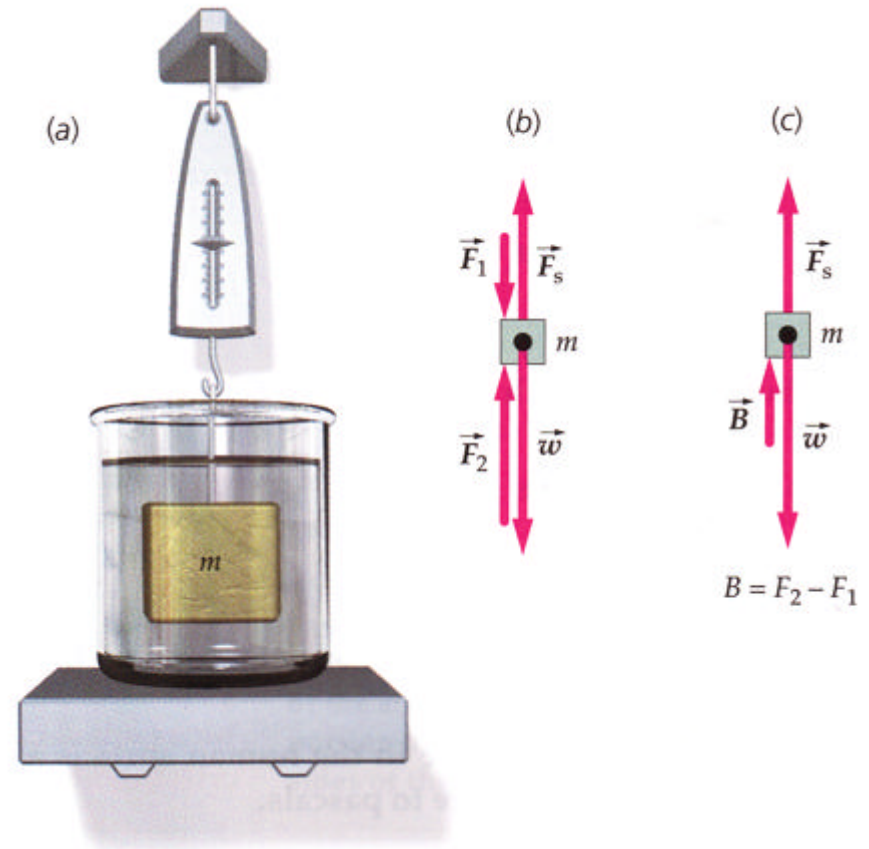
“I don’t understand vectors.”





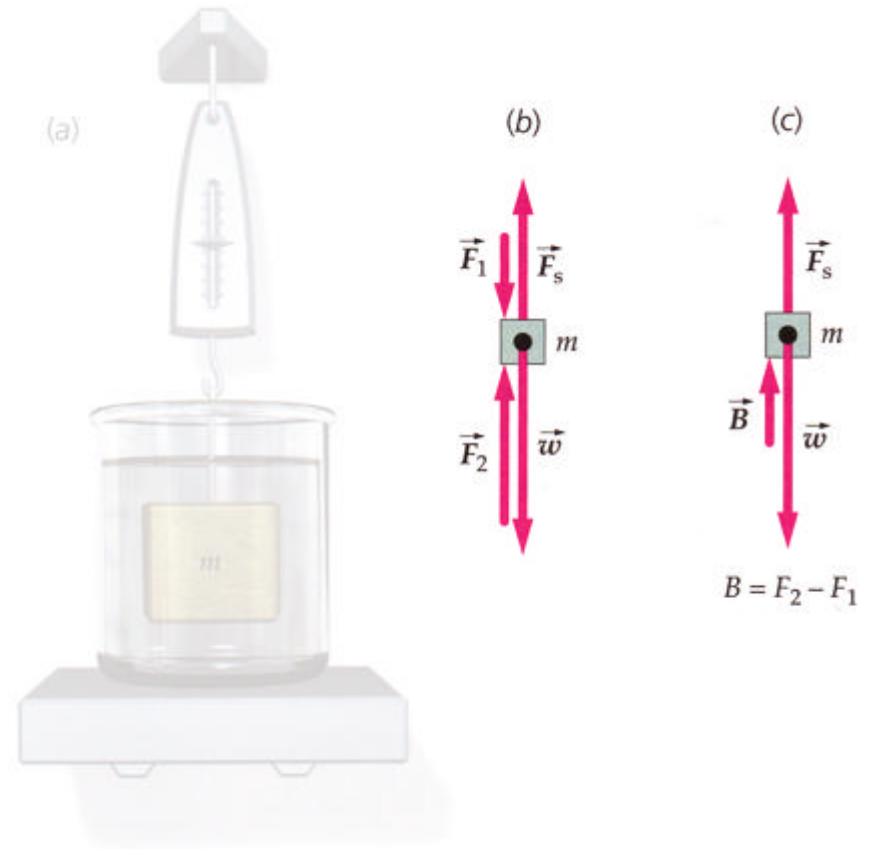
# Working with vectors

We can derive Archimedes' principle from Newton's laws by considering the forces acting on a portion of a fluid and noting that in static equilibrium the net force must be zero. Figure 13-9b shows the vertical forces acting on an object being weighed while submerged. These are the force of gravity  $\vec{w}$  acting down, the force of the spring scale  $\vec{F}_s$  acting up, a force  $\vec{F}_1$  acting down because of the fluid pressure on the top surface of the object, and a force  $\vec{F}_2$  acting up because of the fluid pressing on the bottom surface of the object. Since the spring scale reads a force less than the weight, the force  $\vec{F}_2$  must be greater in magnitude than the force  $\vec{F}_1$ . The difference in magnitude of these two forces is the buoyant force  $\vec{B} = \vec{F}_2 - \vec{F}_1$  (Figure 13-9c). The buoyant force occurs because the pressure of the fluid at the bottom of the object is greater than that at the top.



# Working with vectors

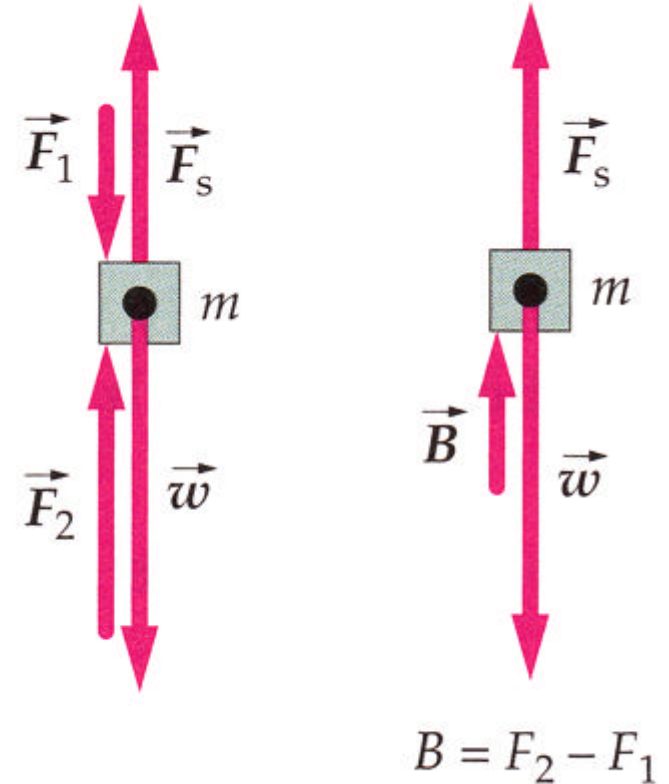
We can derive Archimedes' principle from Newton's laws by considering the forces acting on a portion of a fluid and noting that in static equilibrium the net force must be zero. Figure 13-9b shows the vertical forces acting on an object being weighed while submerged. These are the force of gravity  $\vec{w}$  acting down, the force of the spring scale  $\vec{F}_s$  acting up, a force  $\vec{F}_1$  acting down because of the fluid pressure on the top surface of the object, and a force  $\vec{F}_2$  acting up because of the fluid pressing on the bottom surface of the object. Since the spring scale reads a force less than the weight, the force  $\vec{F}_2$  must be greater in magnitude than the force  $\vec{F}_1$ . The difference in magnitude of these two forces is the buoyant force  $\vec{B} = \vec{F}_2 - \vec{F}_1$  (Figure 13-9c). The buoyant force occurs because the pressure of the fluid at the bottom of the object is greater than that at the top.





# Working with vectors

The difference in magnitude of these two forces is the buoyant force  $\vec{B} = \vec{F}_2 - \vec{F}_1$  (Figure 13-9c).



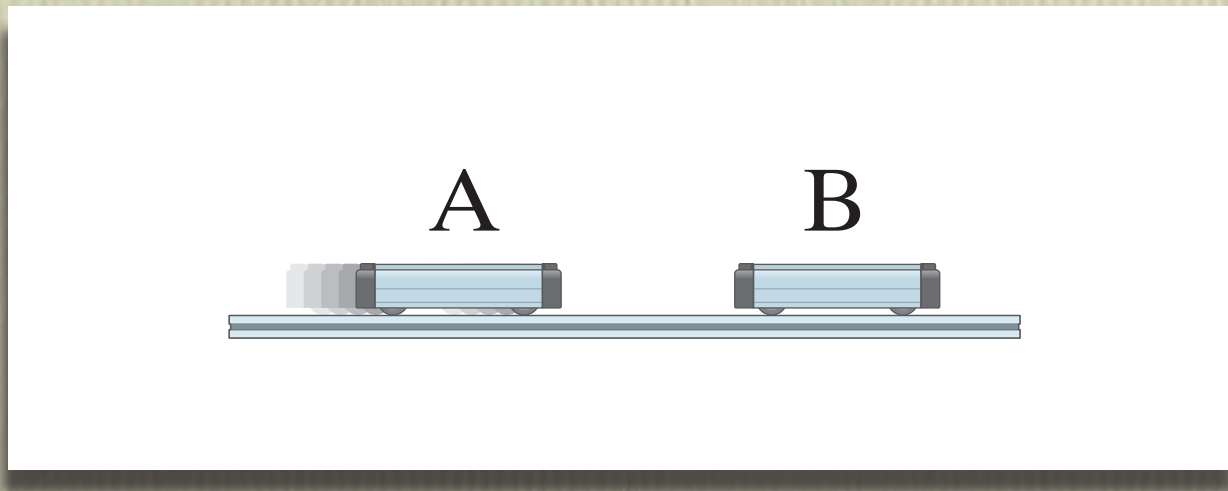
Because we know what is meant,  
we are unconscious of errors

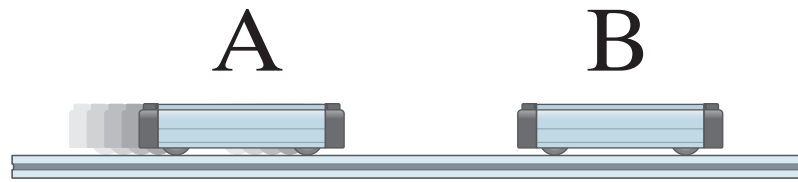




# Conservation

Consider collision on low-friction track





“The momentum of cart B is not conserved”

“Momentum is conserved”

“The total momentum of the carts is constant”

“The momentum of carts A and B is conserved”





To the physicist, all make sense...



...but students are confused!





# Conservation

“I am confused about conservation of momentum”

“Why is momentum not conserved in a nonisolated system?”

“Is momentum conserved in an inelastic collision?”

“I am confused as to how (and when) to apply conservation of momentum”



# Conservation

Involves many concepts

- System (universe, environment)
- Extensive quantities
- Destruction/creation
- Interactions (transfer, flow, boundary)
- Constant (no change over time)





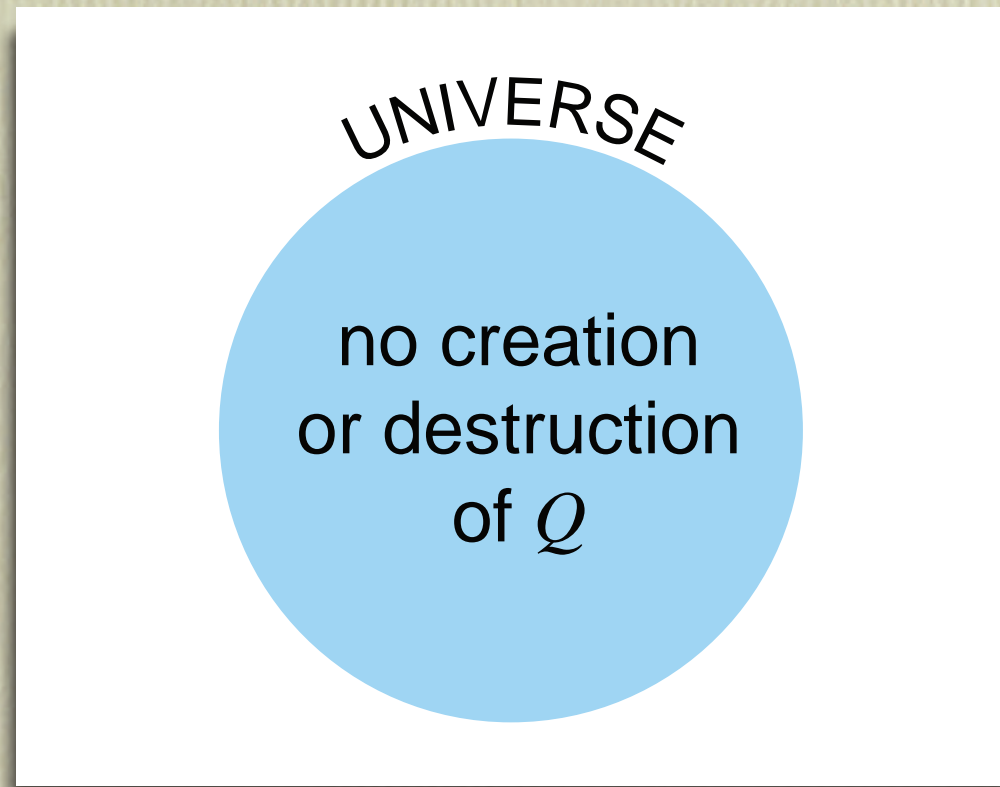
# Conservation

How to express “conservation” of quantity  $Q$ ?



# Conservation

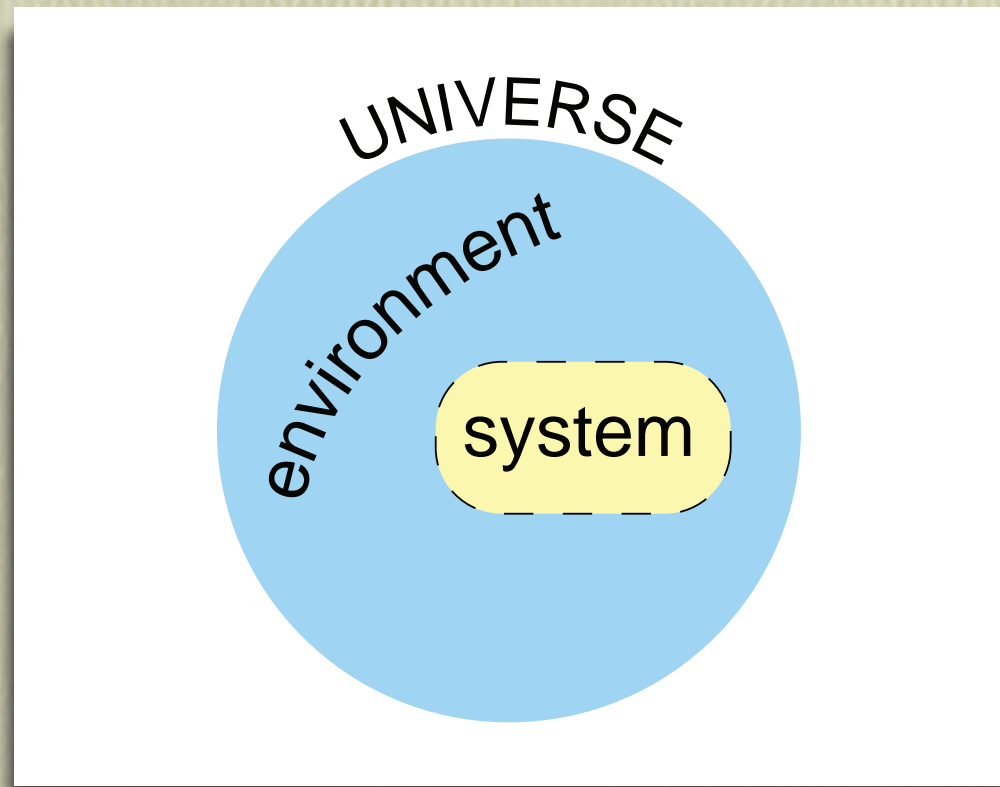
How to express “conservation” of quantity  $Q$ ?





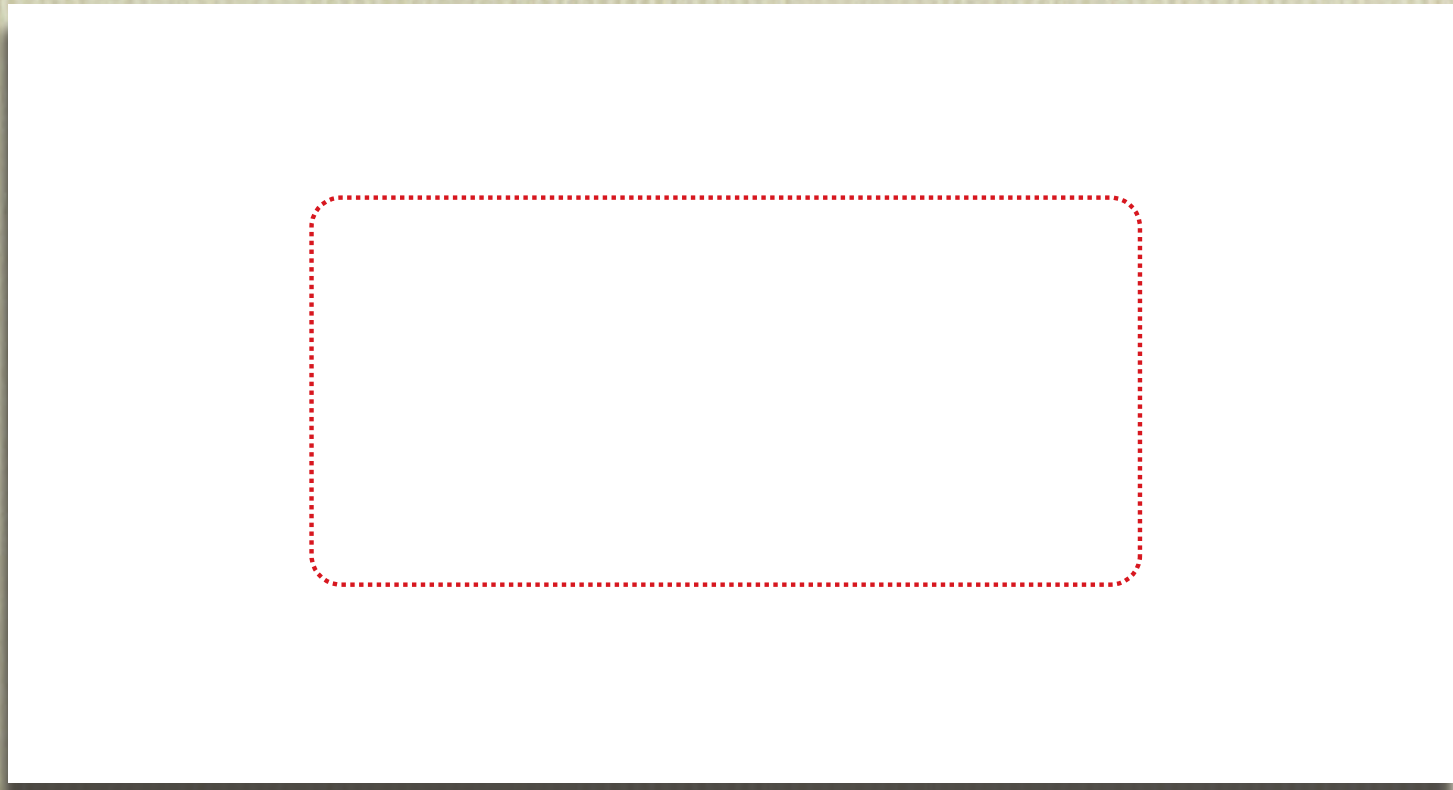
# Conservation

How to express “conservation” of quantity  $Q$ ?



# Conservation

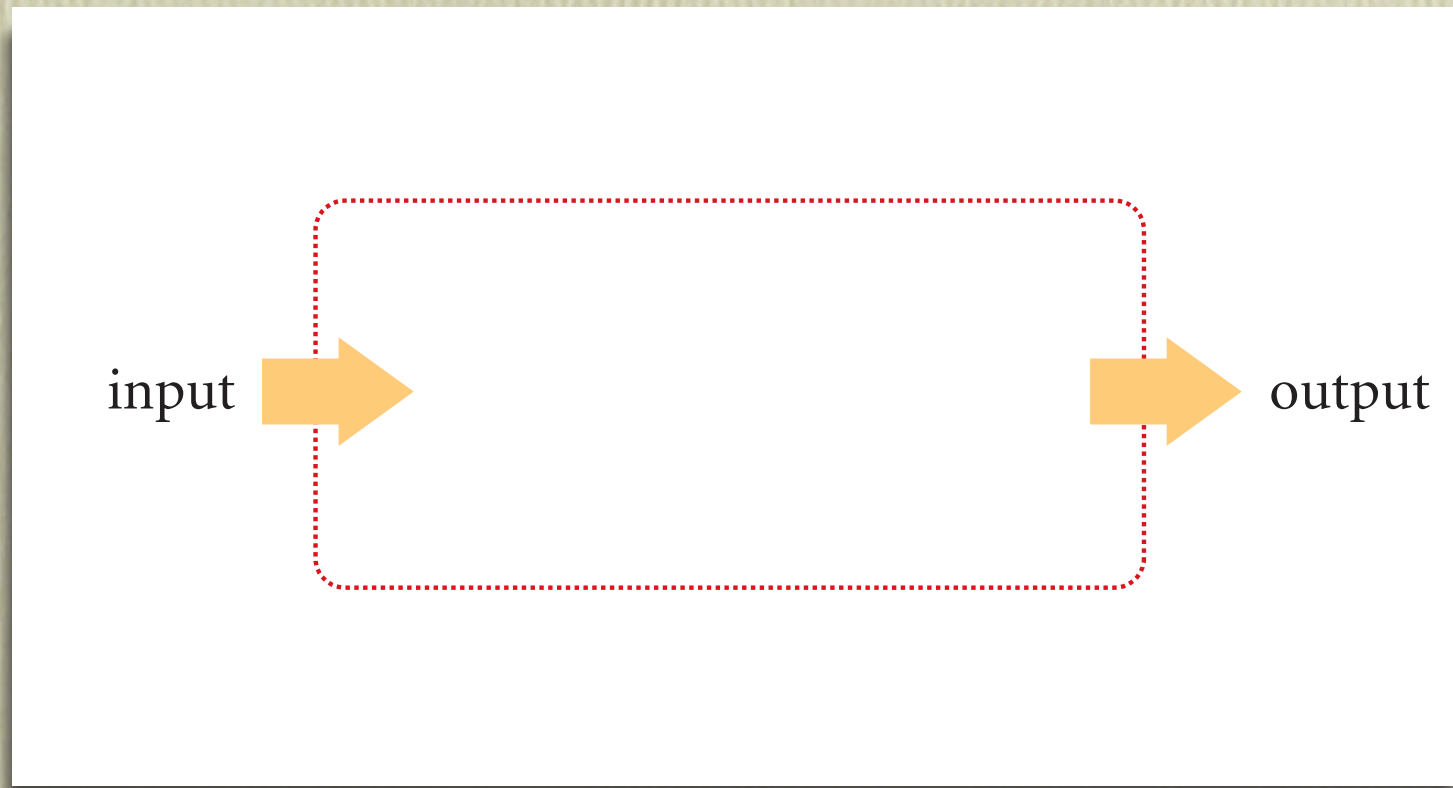
How can  $Q$  change?





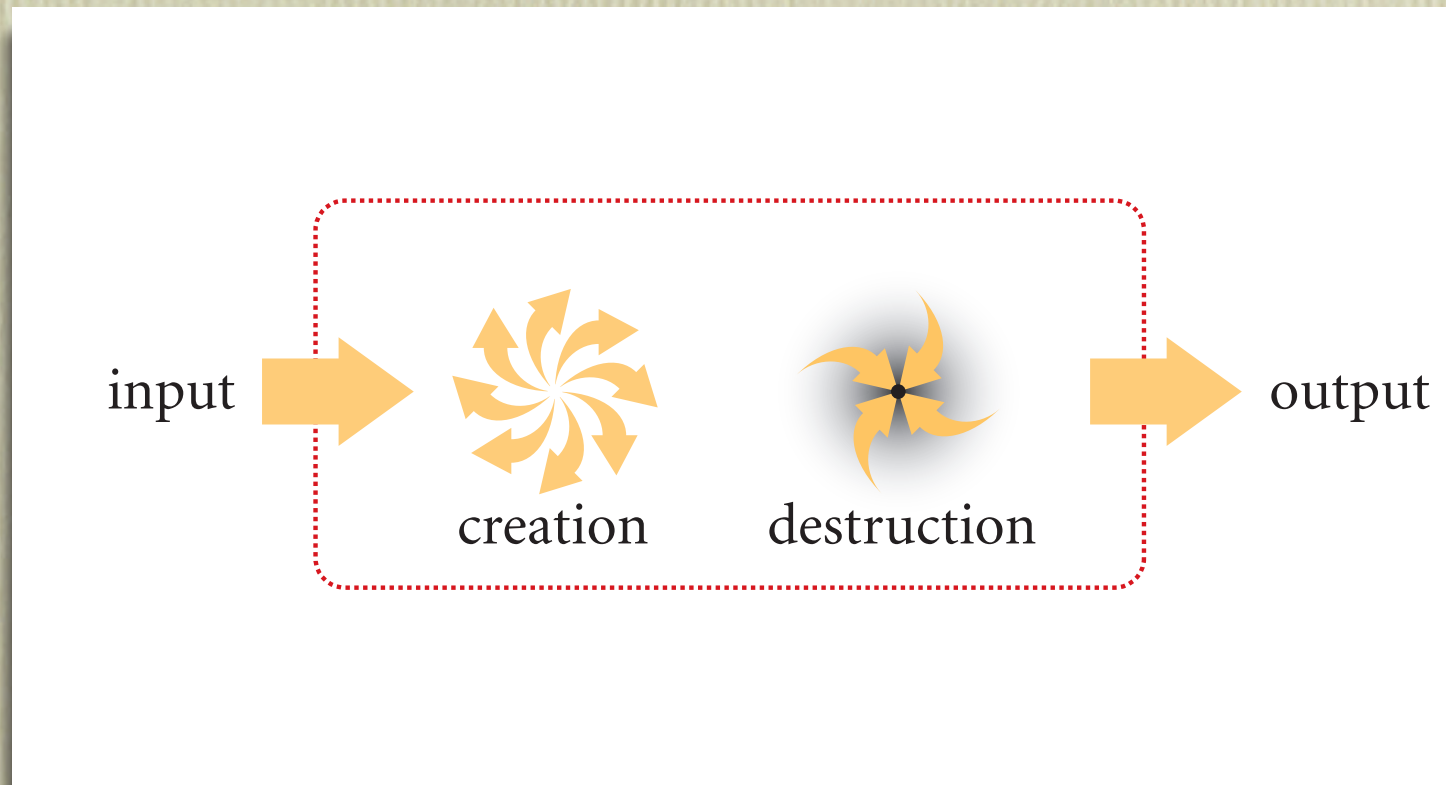
# Conservation

How can  $Q$  change?



# Conservation

How can  $Q$  change?





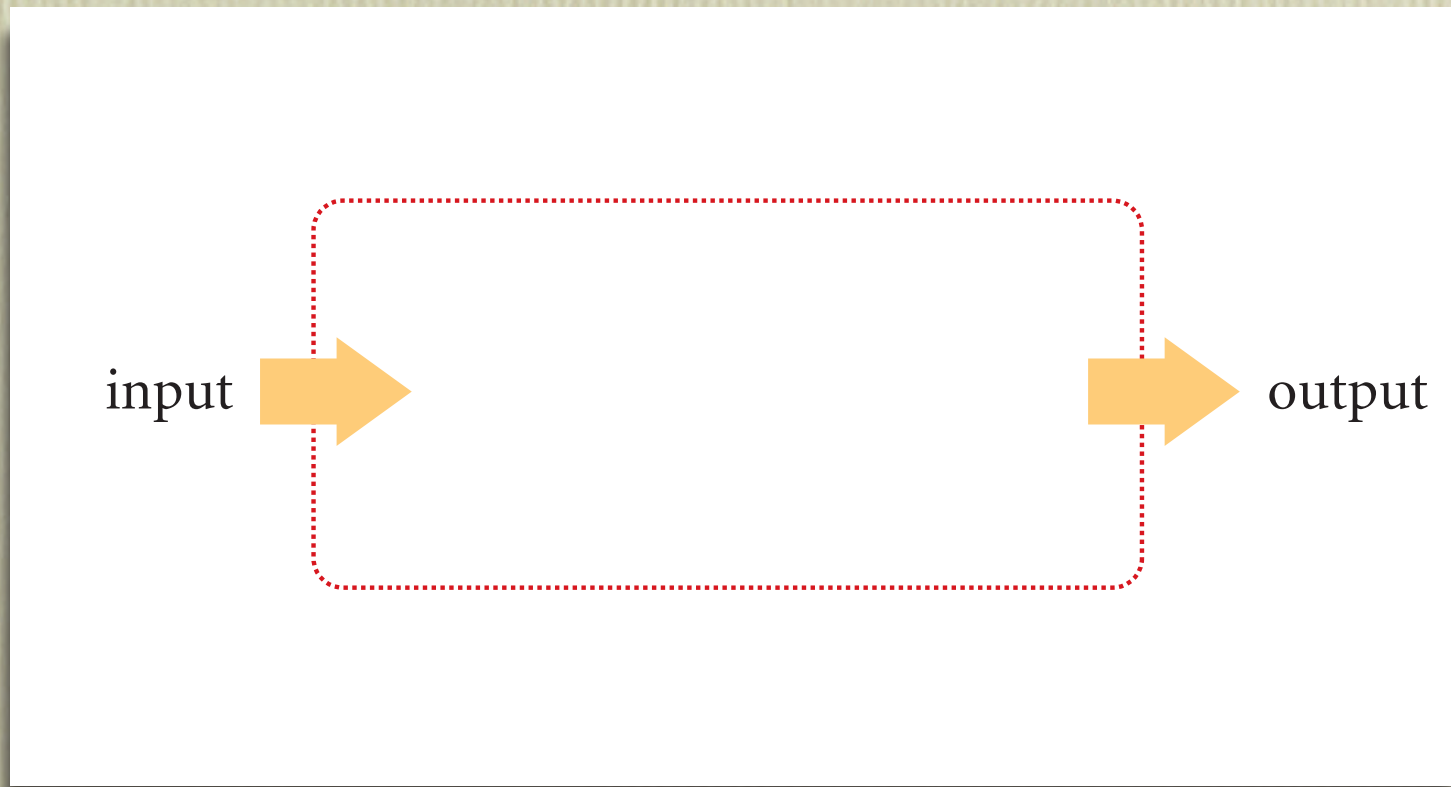
# Conservation

$$\Delta Q = J_Q + S_Q$$



# Conservation

If  $Q$  is “conserved”:  $S_Q = 0$ , and so  $\Delta Q = J_Q$





# Conservation

If system *also* isolated:  $J_Q = 0$ , and so  $\Delta Q = 0$

$Q$  cannot change



# Conservation

conservation + isolation = no change

$Q$  cannot change





# Conservation

What I told my students:



# Conservation

What I told my students:

I. Conservation laws most basic principles





# Conservation

What I told my students:

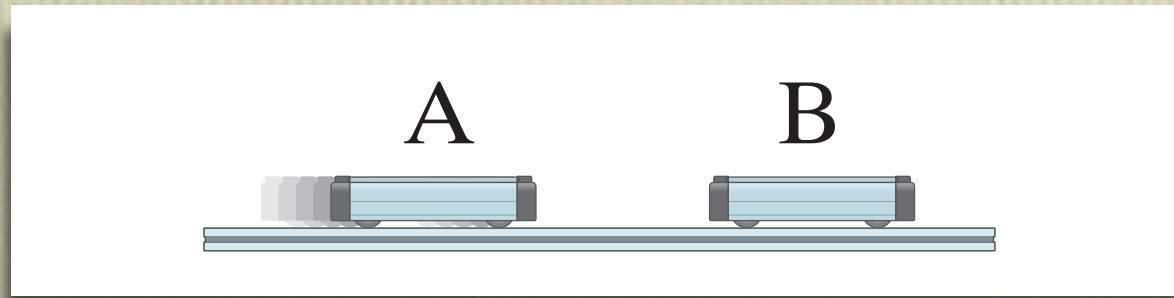
1. Conservation laws most basic principles
2. Momentum is conserved



# Conservation

What I told my students:

1. Conservation laws most basic principles
2. Momentum is conserved

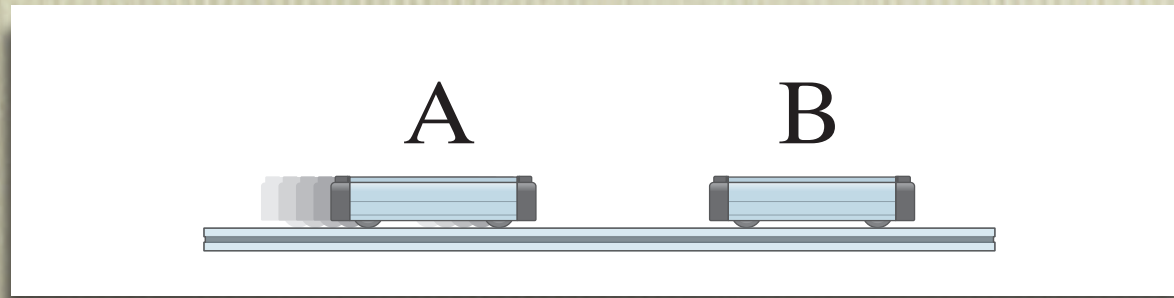




# Conservation

What I told my students:

1. Conservation laws most basic principles
2. Momentum is conserved



3. Momentum of cart *B* is not conserved



*Dear Professor,*

*If conservation is so fundamental,  
then why is momentum  
conserved only in certain cases?*

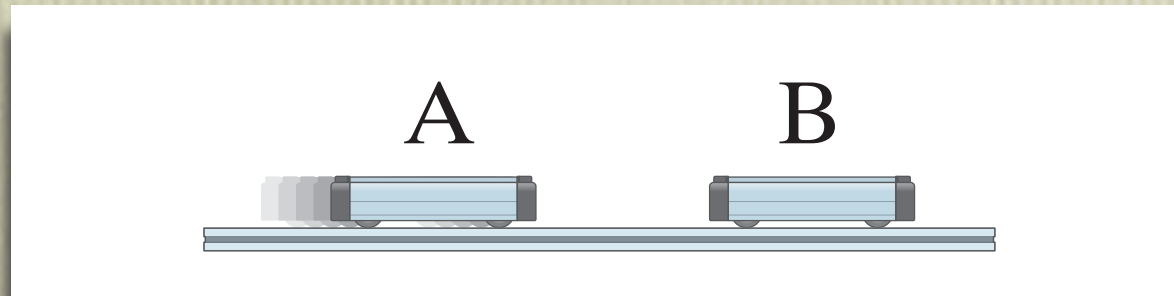




# Conservation

What I should have said instead:

1. Conservation laws most basic principles
2. Momentum is conserved



3. Momentum of cart *B* is not **constant**



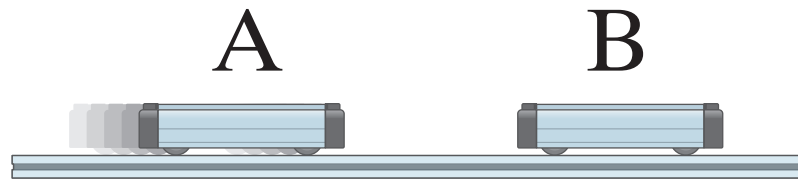
# Conservation

A conserved quantity:

1. is *always* conserved
2. is *constant* (not *conserved*) for isolated systems
3. can *only* change due to transfer across boundary







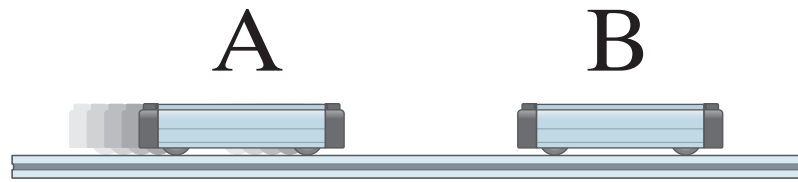
“The momentum of cart B is not conserved”

“Momentum is conserved”

“The total momentum of the carts is constant”

“The momentum of carts A and B is conserved”





“The momentum of cart B is not **constant**”

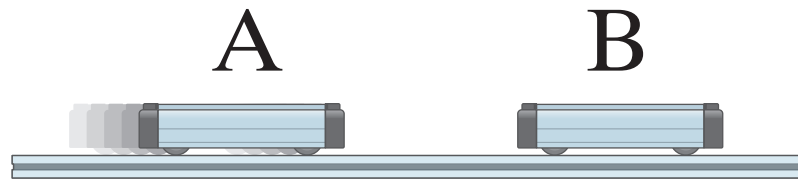
“Momentum is conserved”

“The total momentum of the carts is constant”

“The momentum of carts A and B is conserved”







“The momentum of cart B is not **constant**”

“Momentum is conserved”

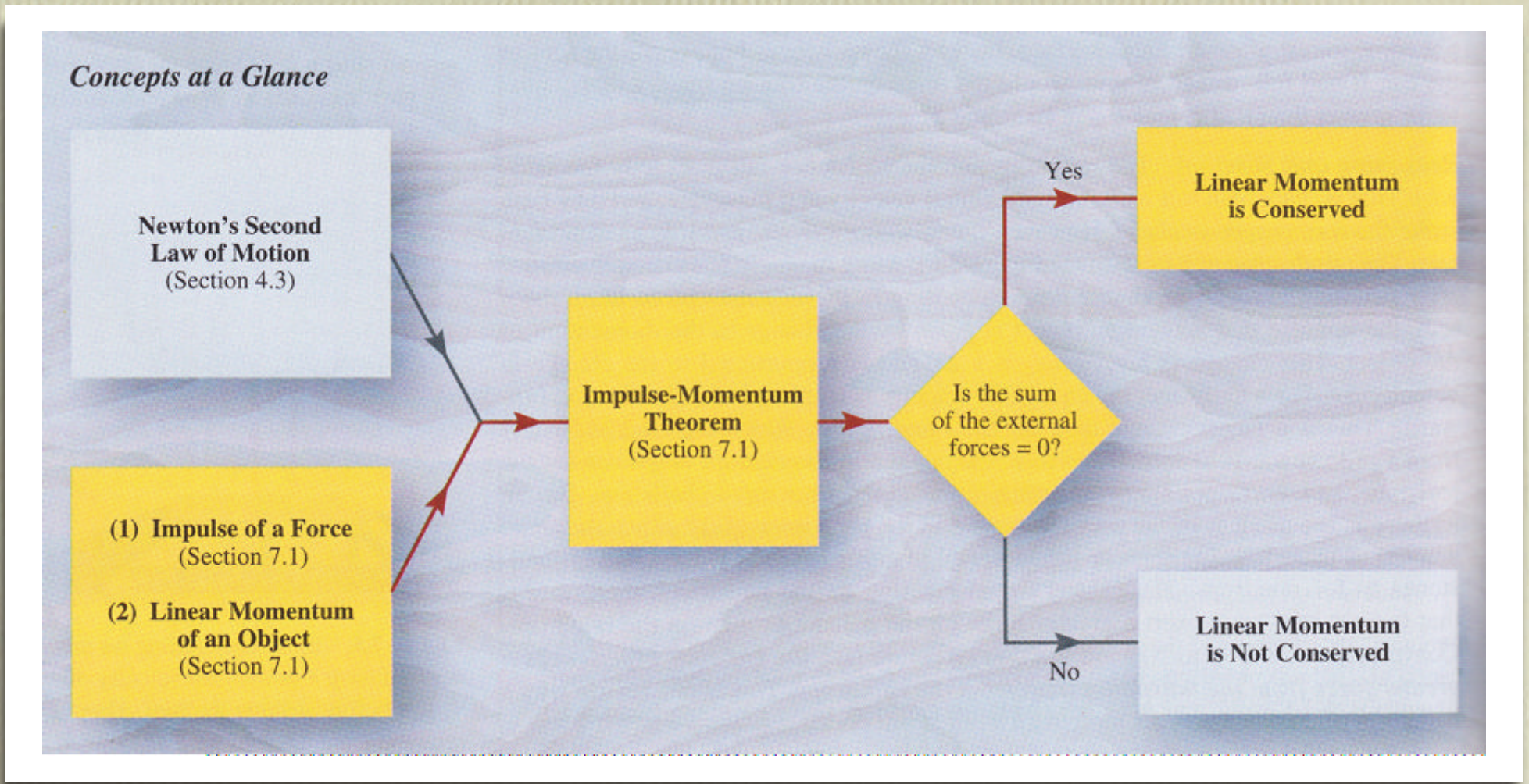
“The total momentum of the carts is constant”

“The momentum of carts A and B is **constant**”



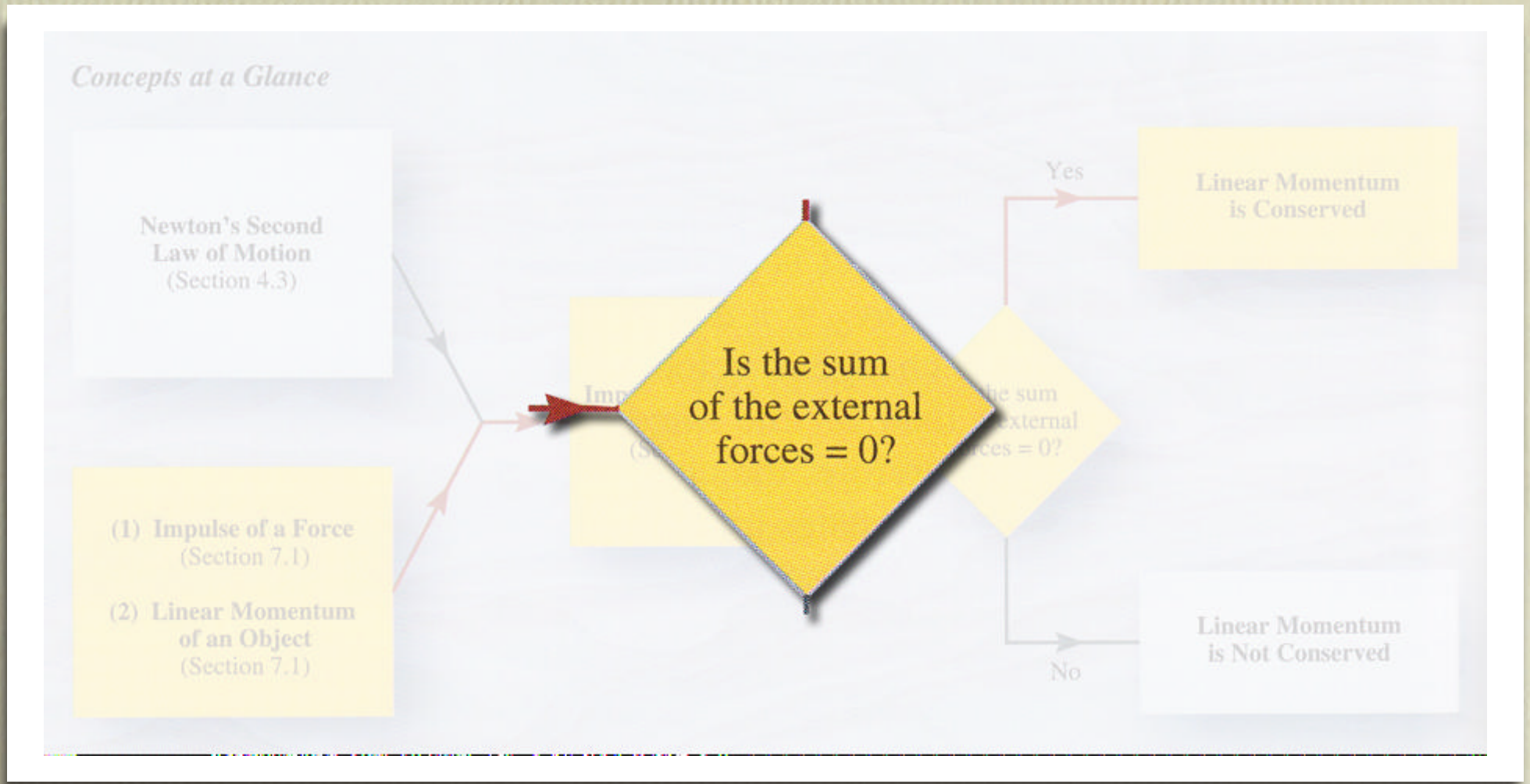


# It's not just me!

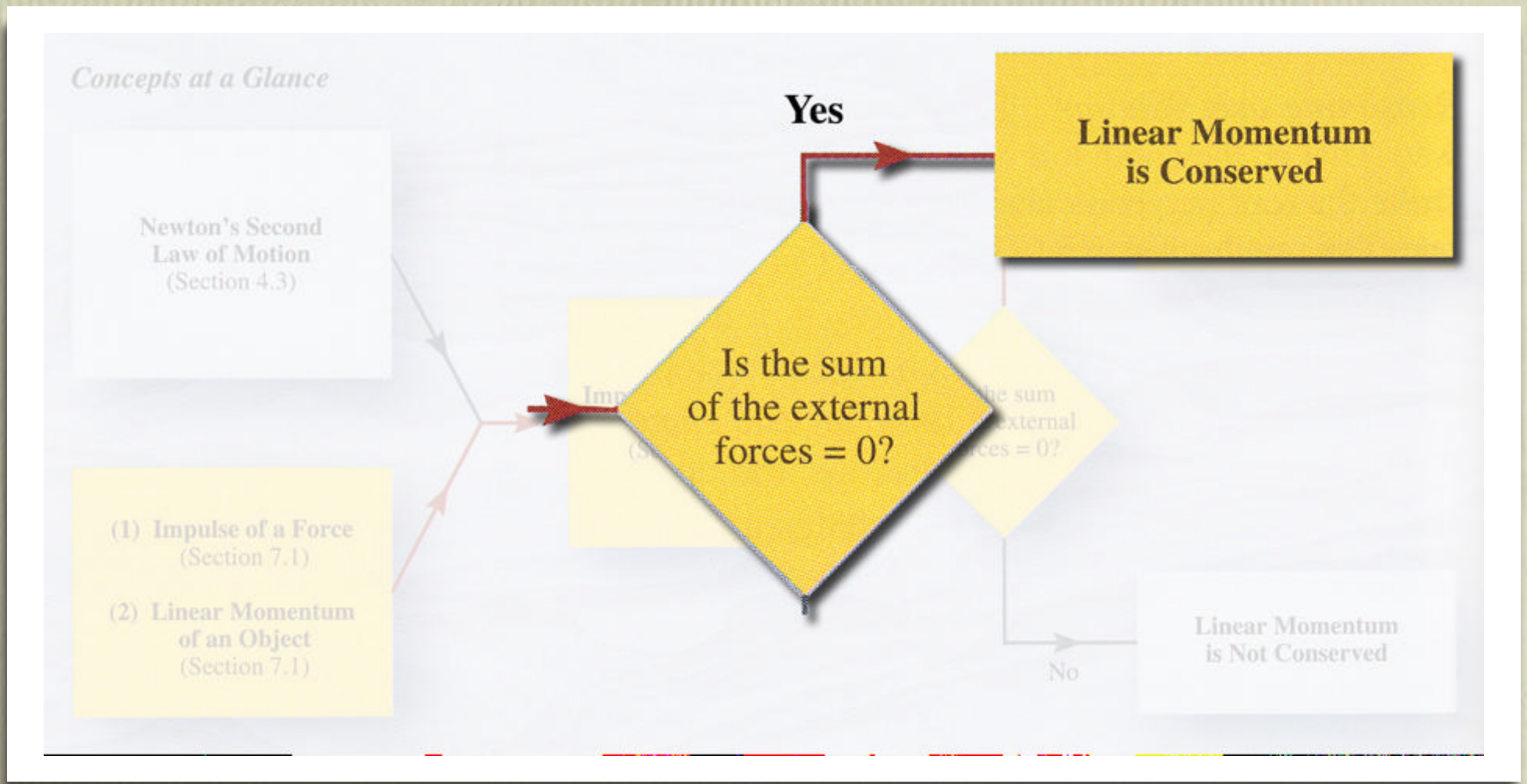




# It's not just me!

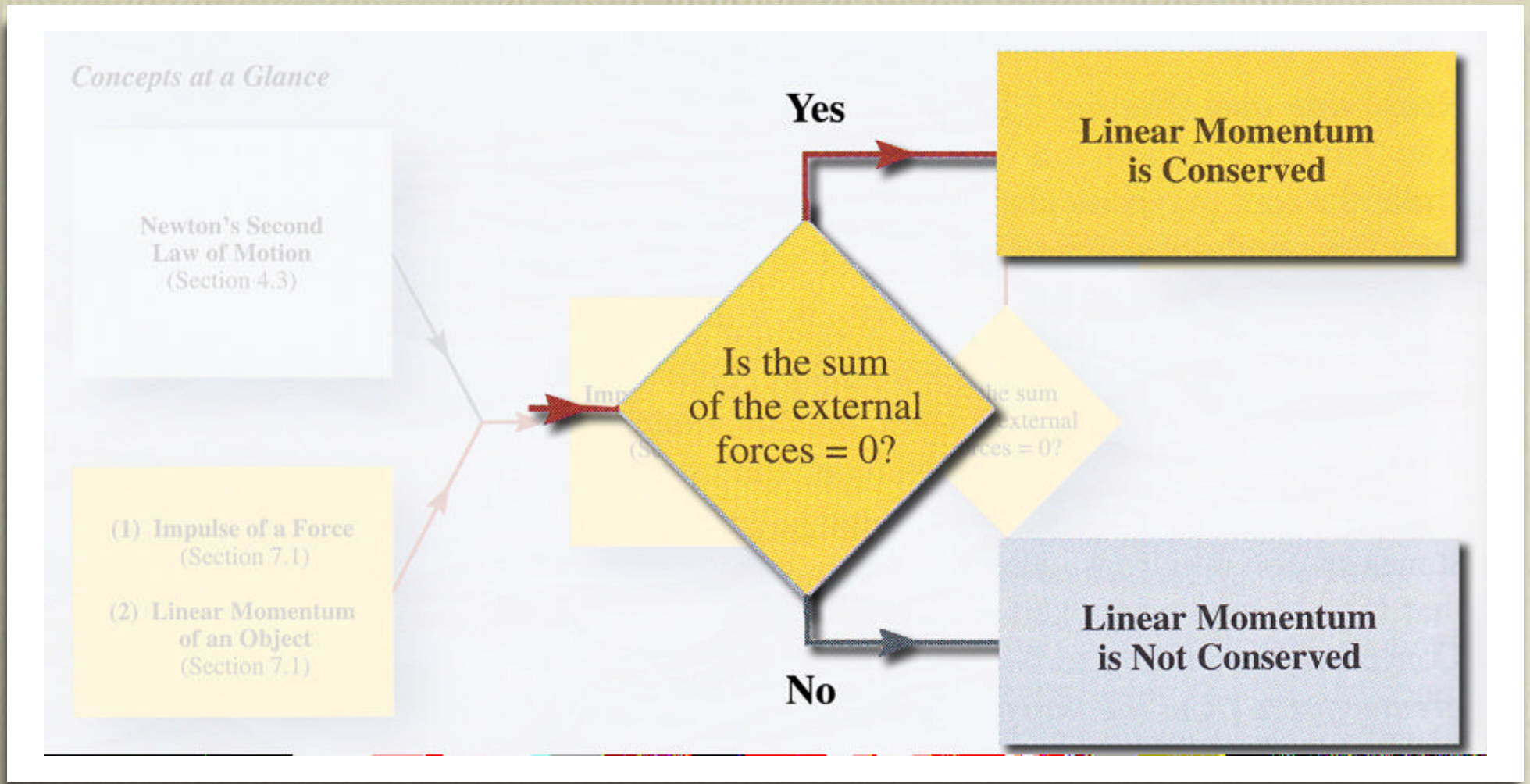


# It's not just me!





# It's not just me!




Lack of precision leads to confusion



# Summary

- Silly art makes us look weird
- Misplaced realism makes physics different
- Lack of precision confuses



We need to be more careful  
with our own representations



*Dear Professor,*

*Dear Professor,*

*You keep saying that science  
is all about proof.*



*Dear Professor,*

*You keep saying that science  
is all about proof.*

*If you prove that what we believe is wrong,  
we should change our minds.*

*Dear Professor,*

*You keep saying that science  
is all about proof.*

*If you prove that what we believe is wrong,  
we should change our minds.*

*But minds don't change like that.*



*Dear Professor,*

*You keep saying that science  
is all about proof.*

*If you prove that what we believe is wrong,  
we should change our minds.*

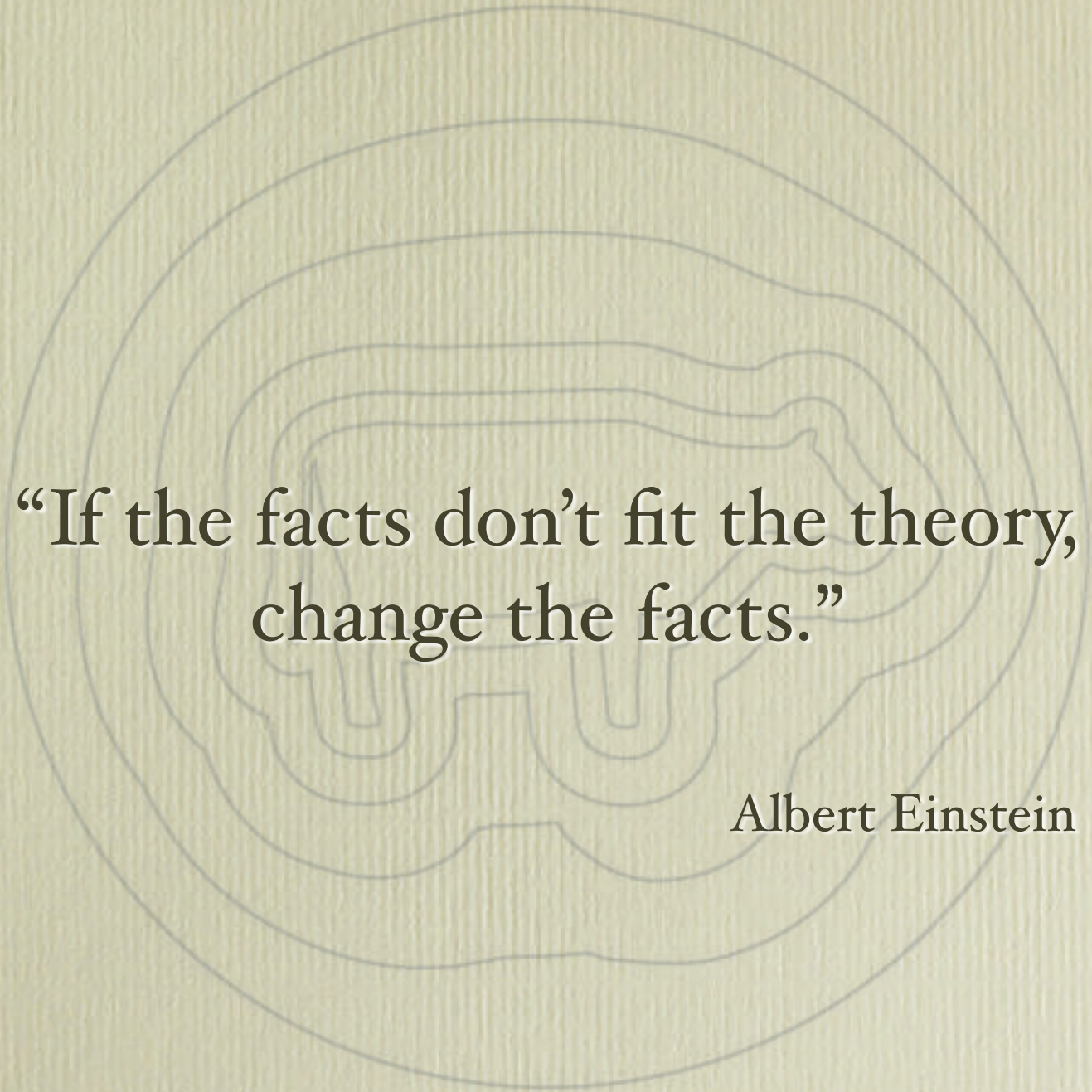
*But minds don't change like that.*

*We keep proving it  
every time we take another test.*

Nin Andrews, *Dear Professor* (Subito Press, 2008)







“If the facts don’t fit the theory,  
change the facts.”

Albert Einstein

