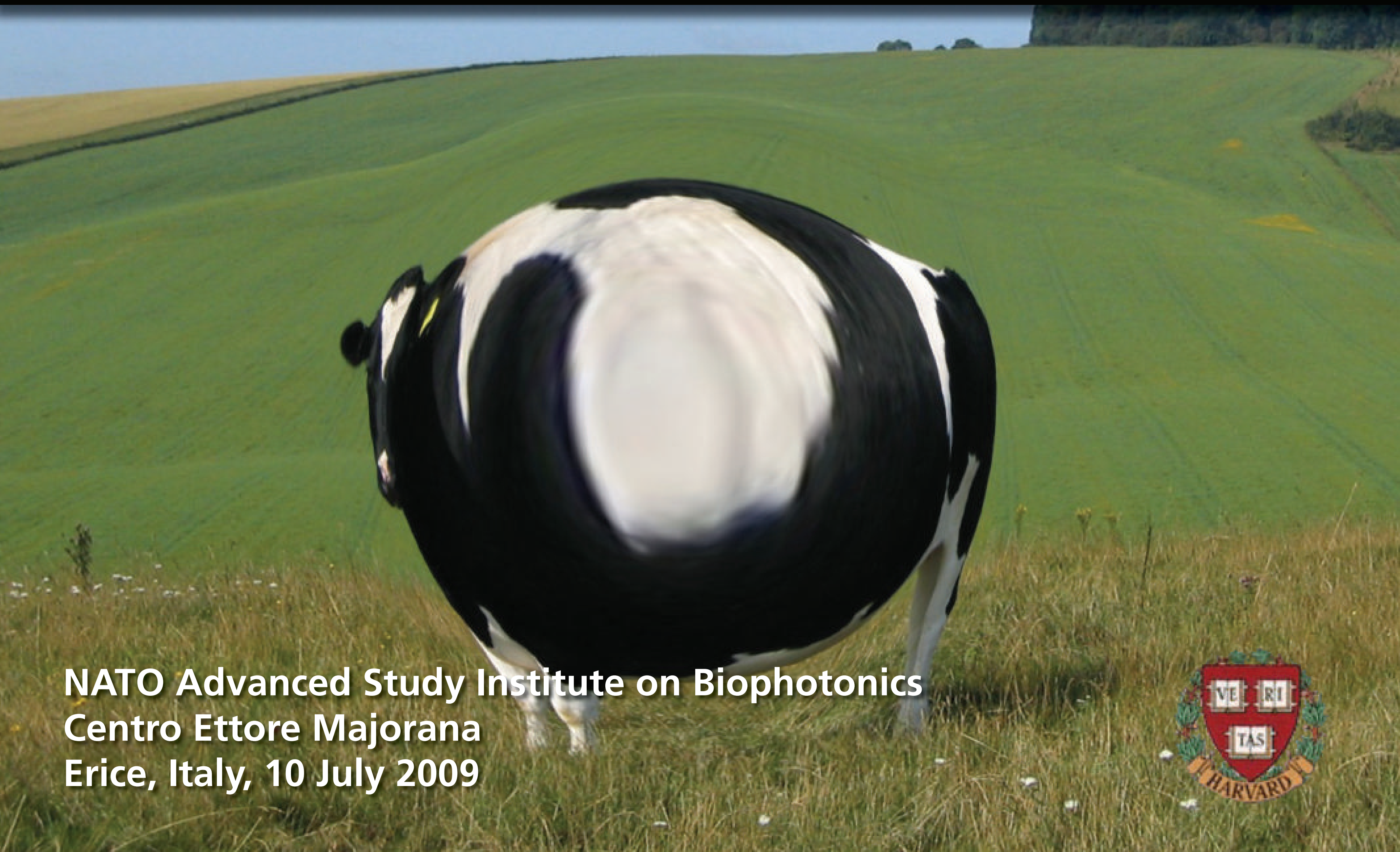
The make-believe world of real-world physics



NATO Advanced Study Institute on Biophotonics
Centro Ettore Majorana
Erice, Italy, 10 July 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?

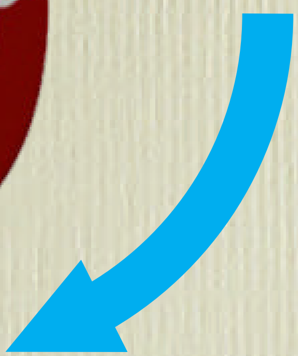
physicists

lay people

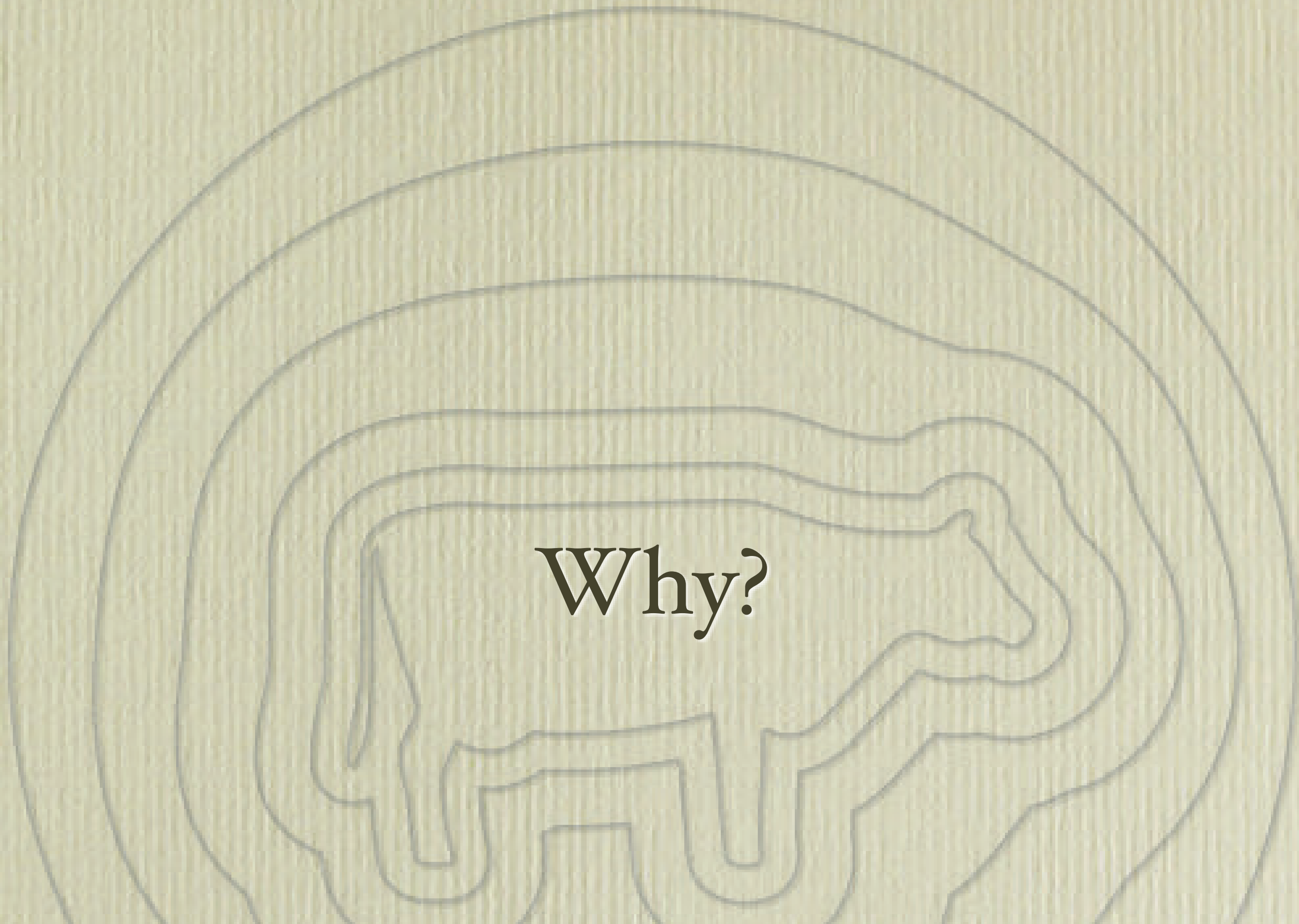
Does physics apply to the real world?

physicists

lay people

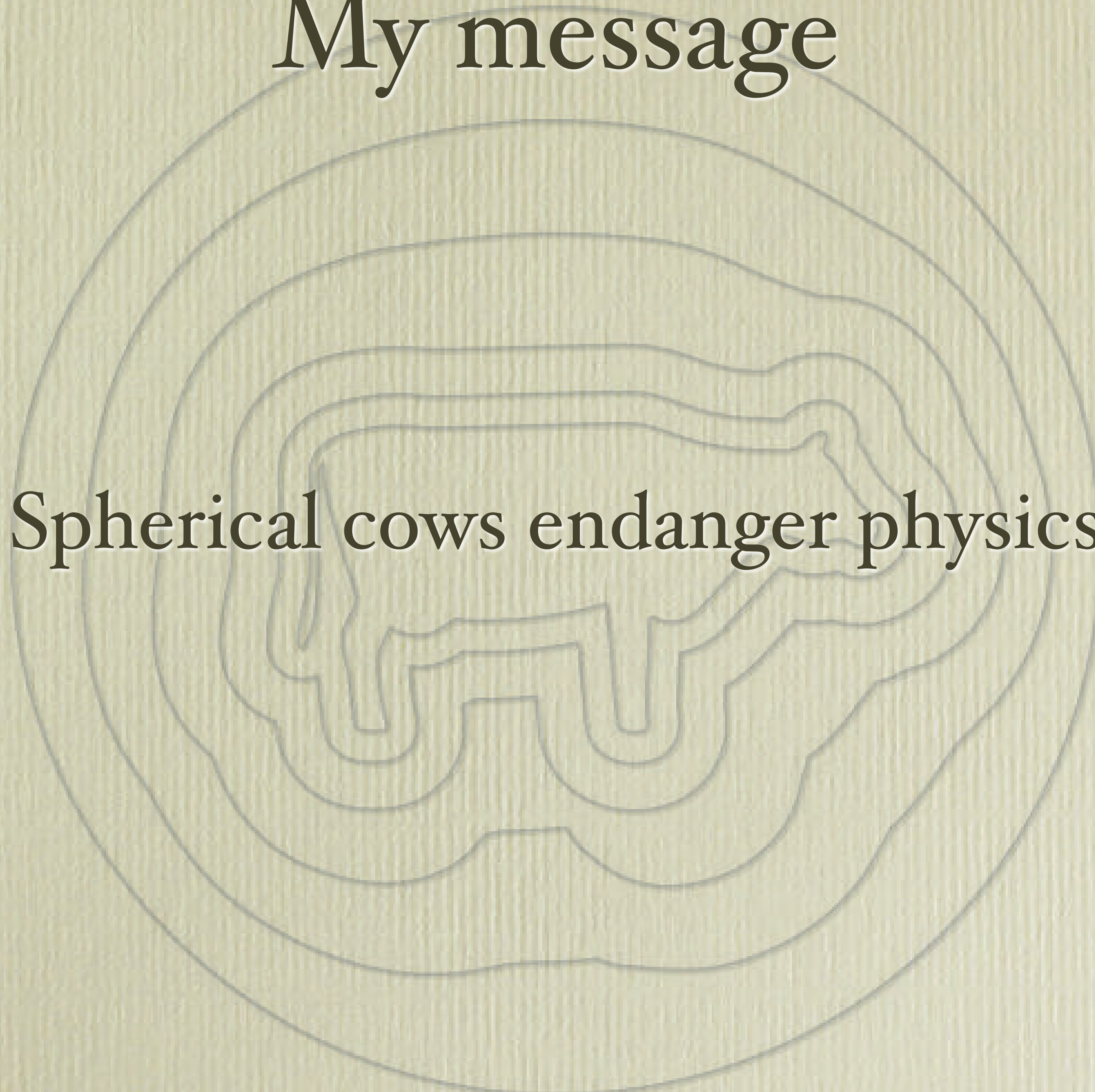


students



Why?

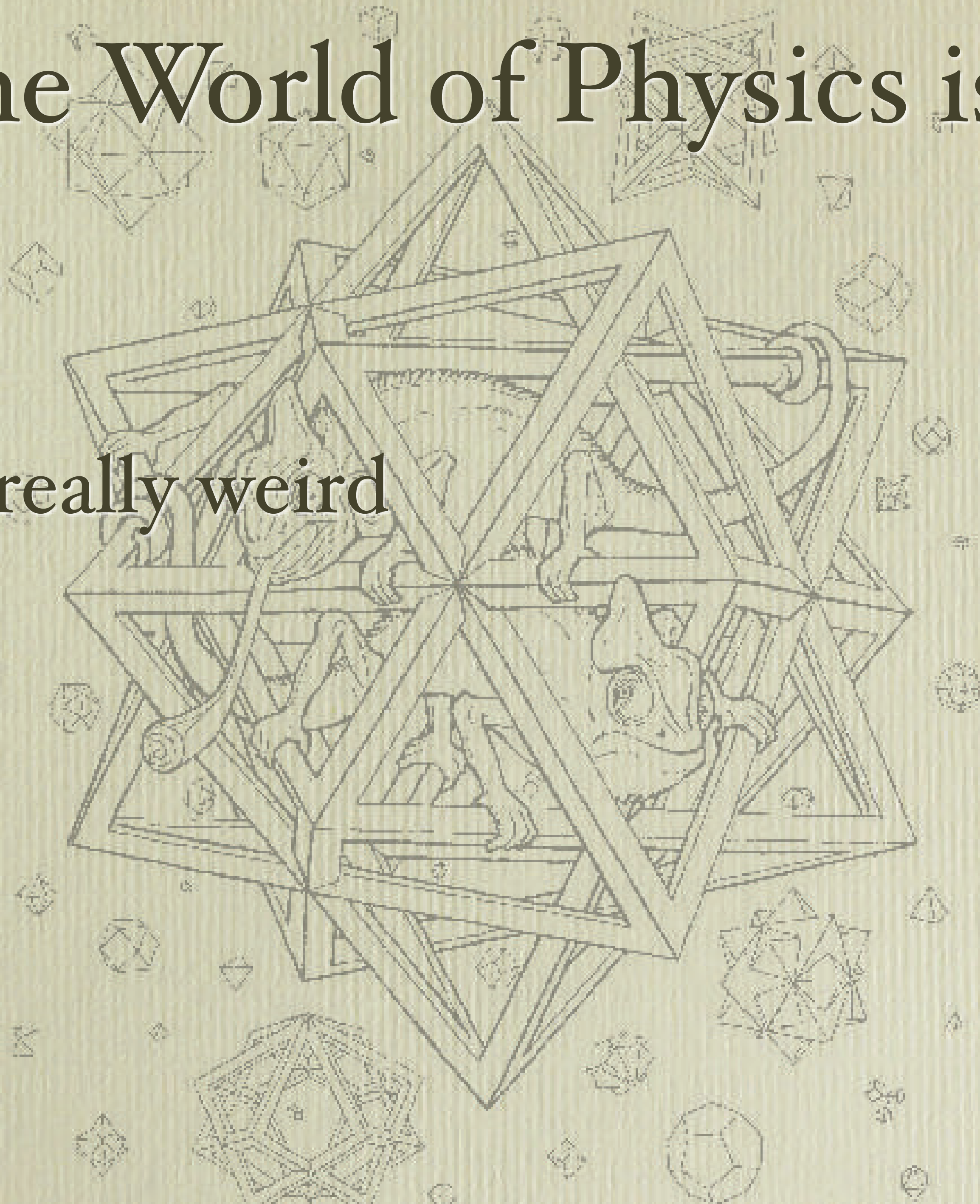
My message



Spherical cows endanger physics

The World of Physics is...

- really weird



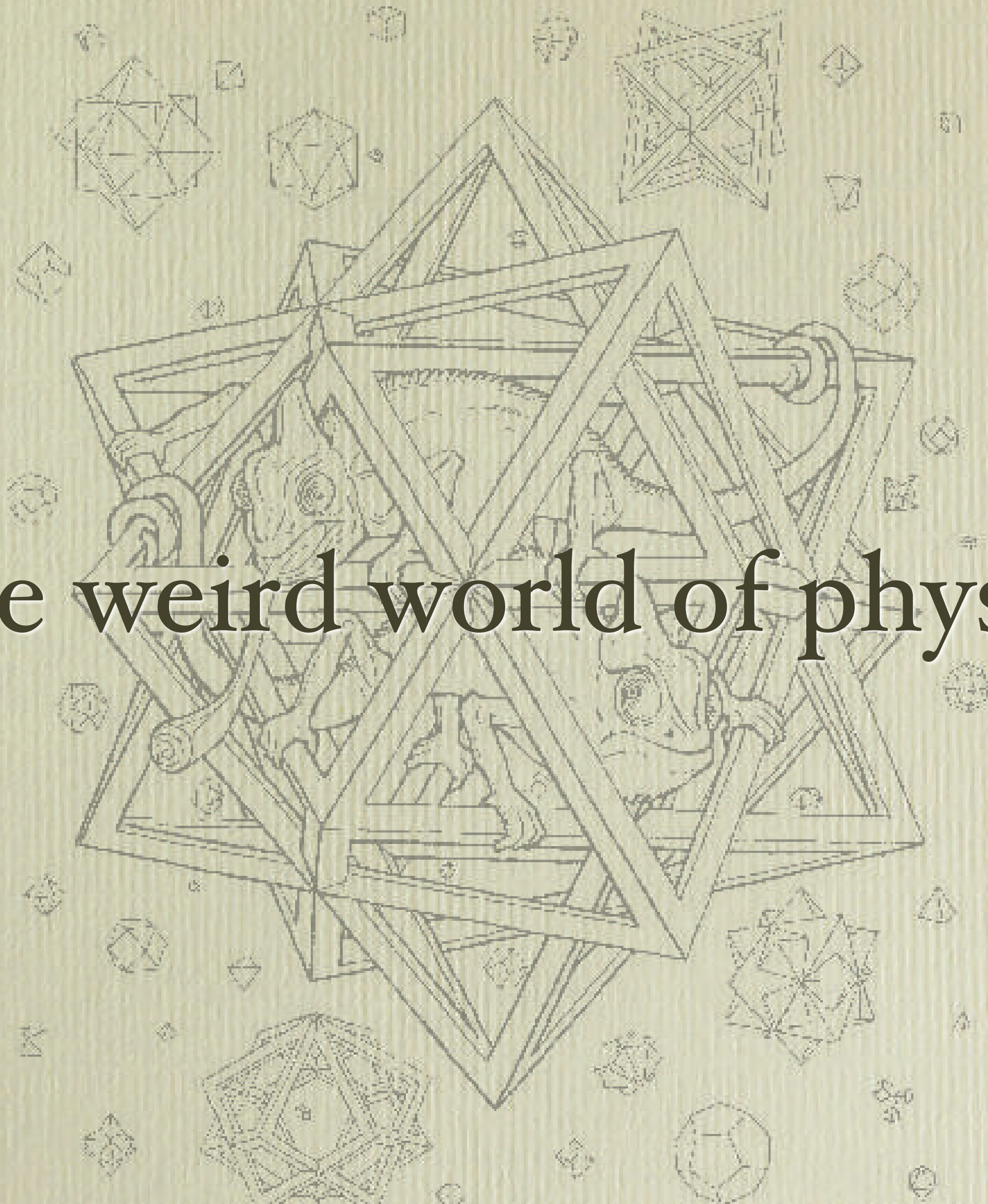
The World of Physics is...

- 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

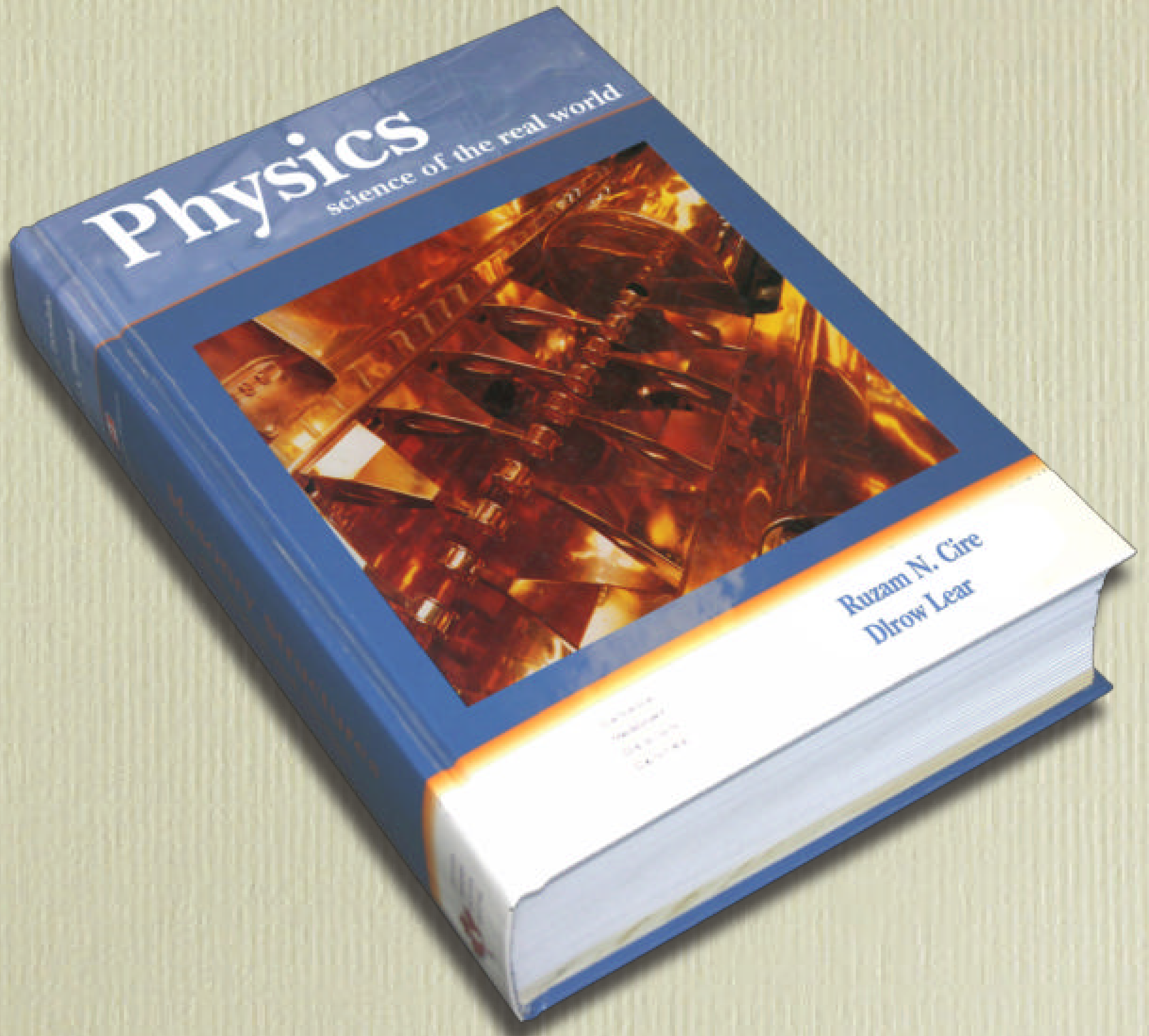


Table manners

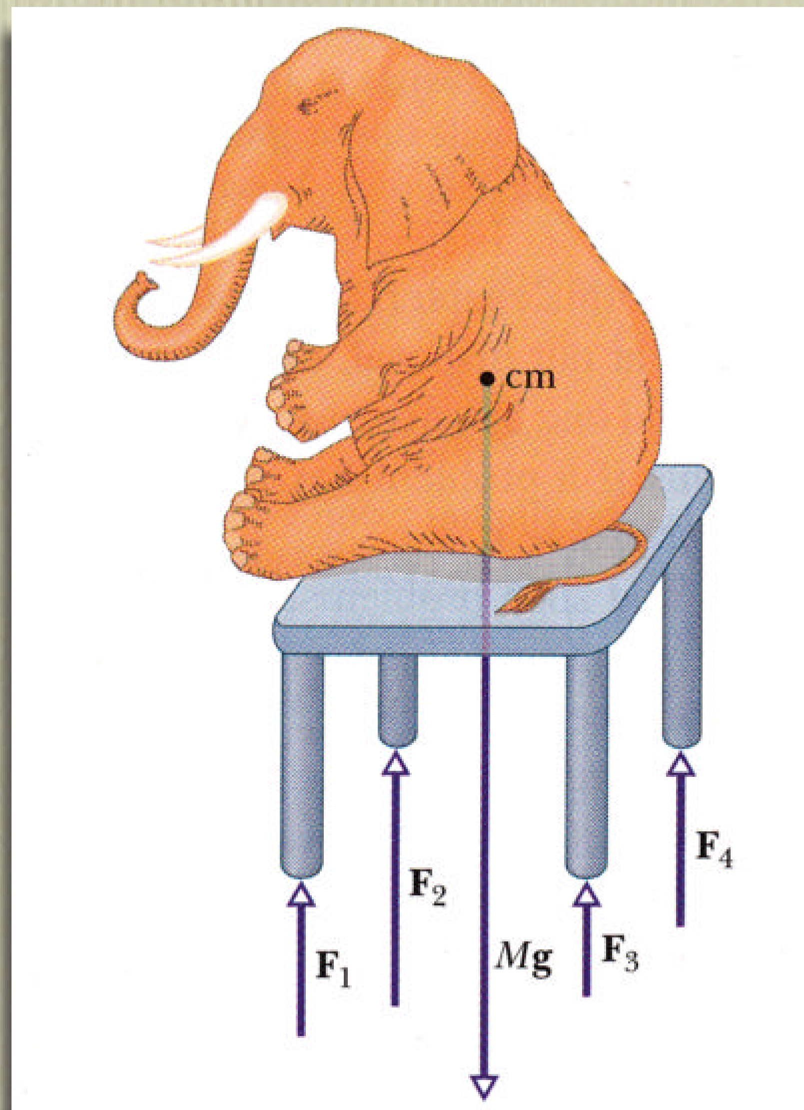
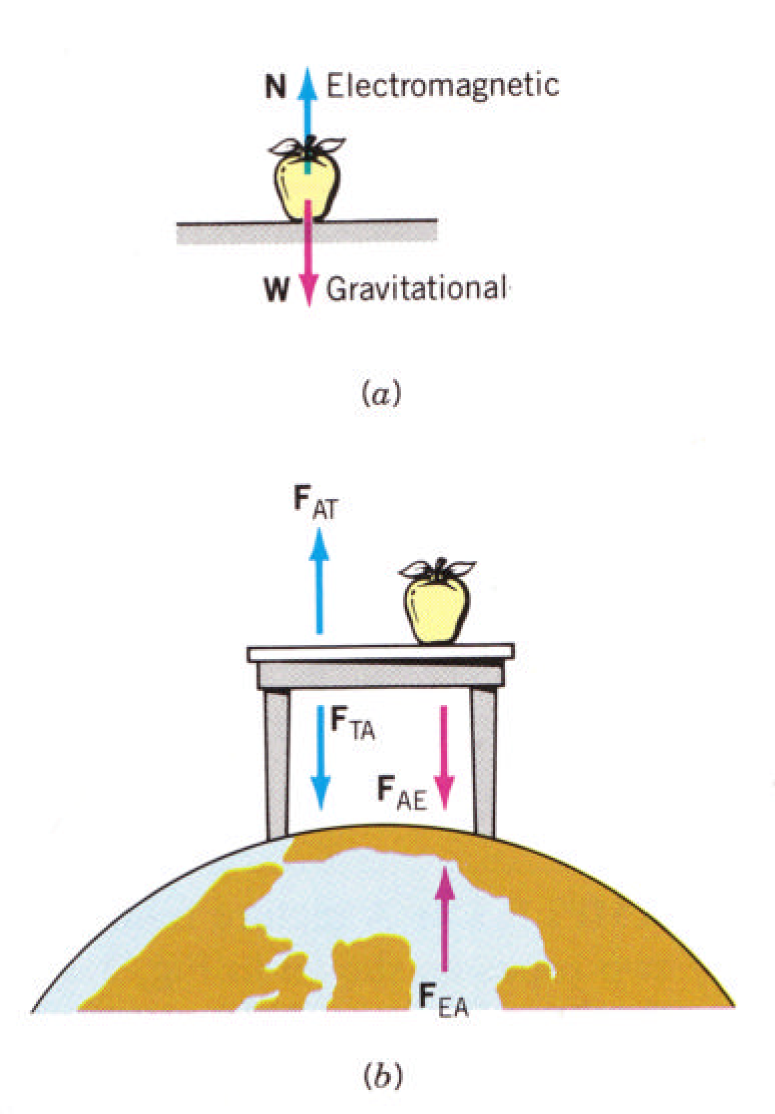
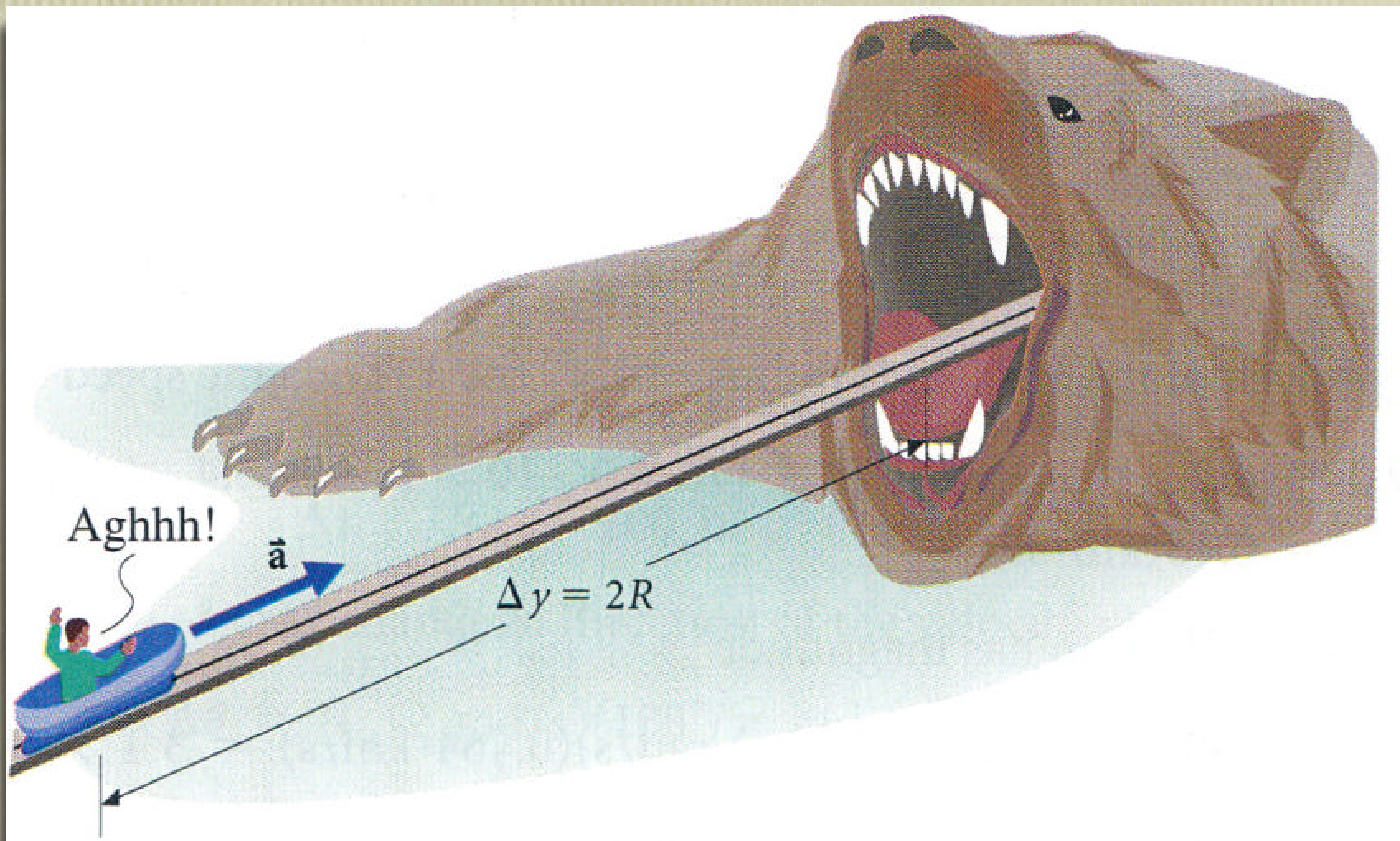


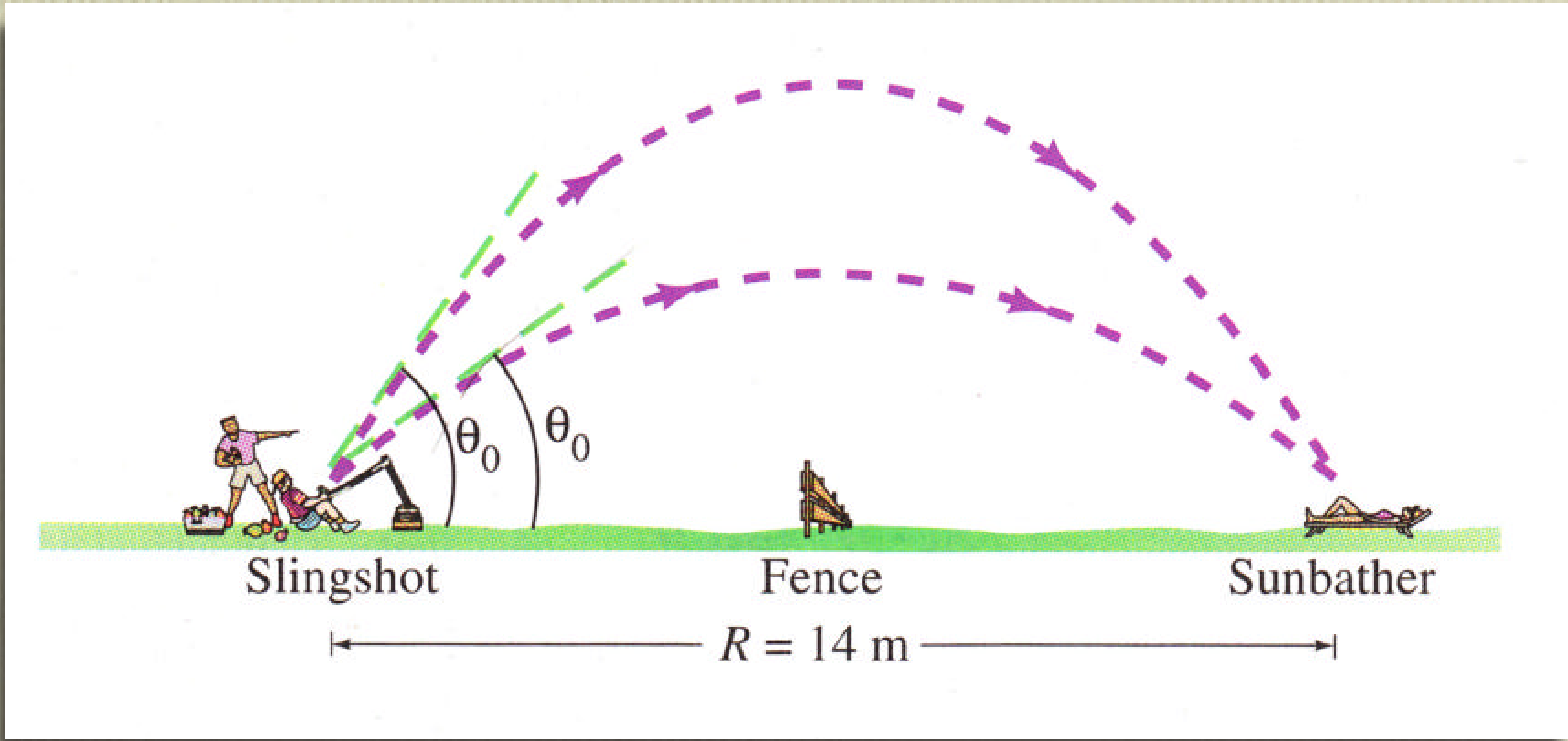
Table manners



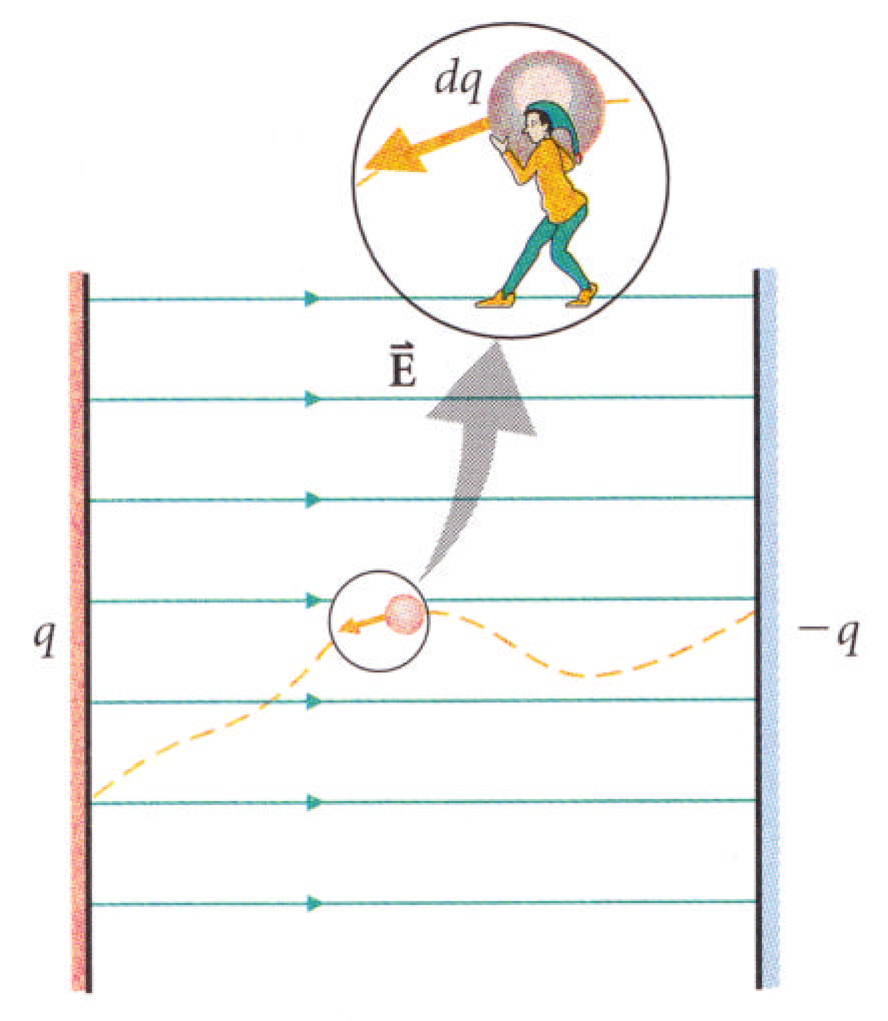
Leisure time activities



Leisure time activities



Leisure time activities



Leisure time activities

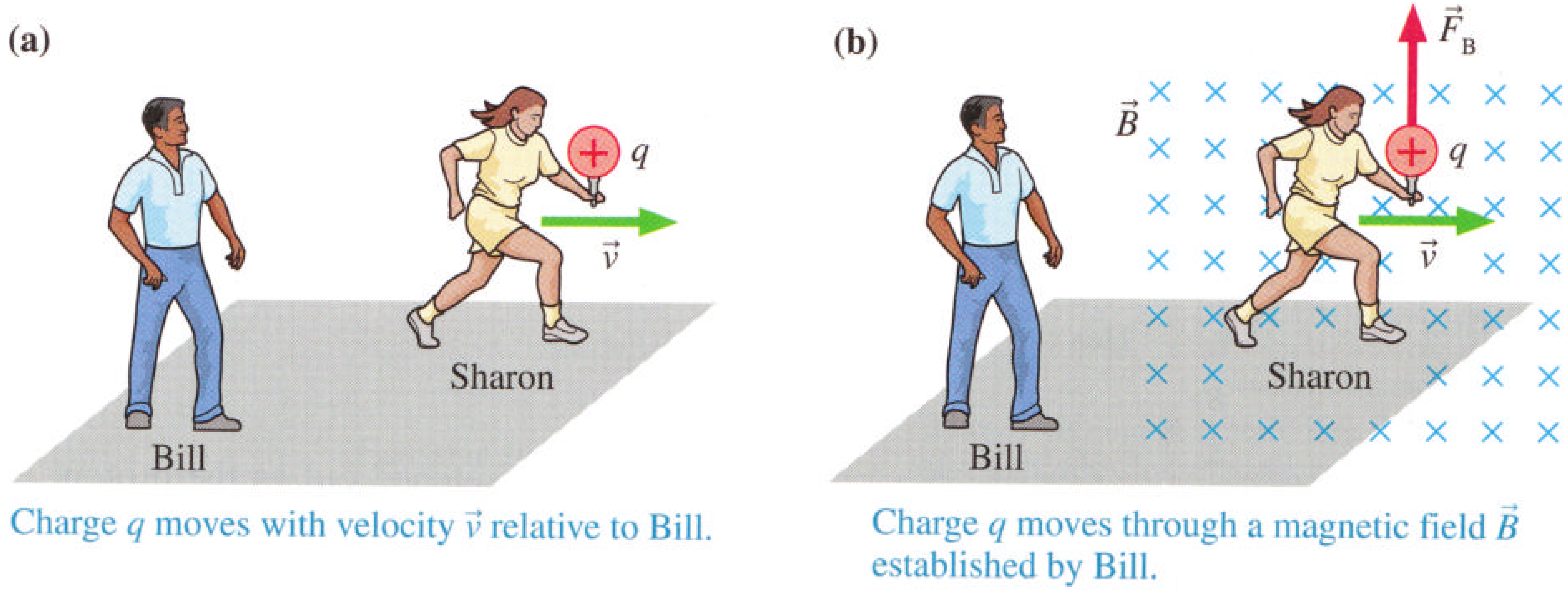
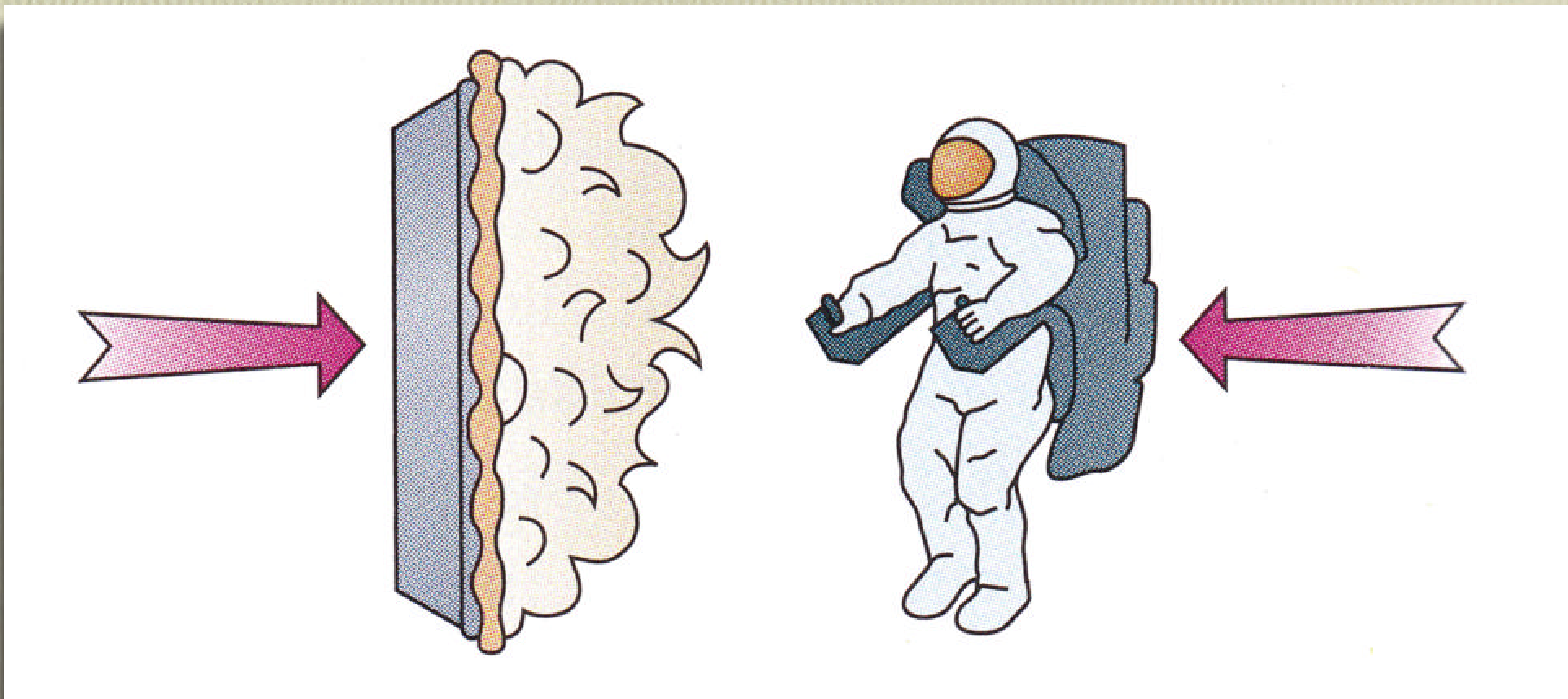


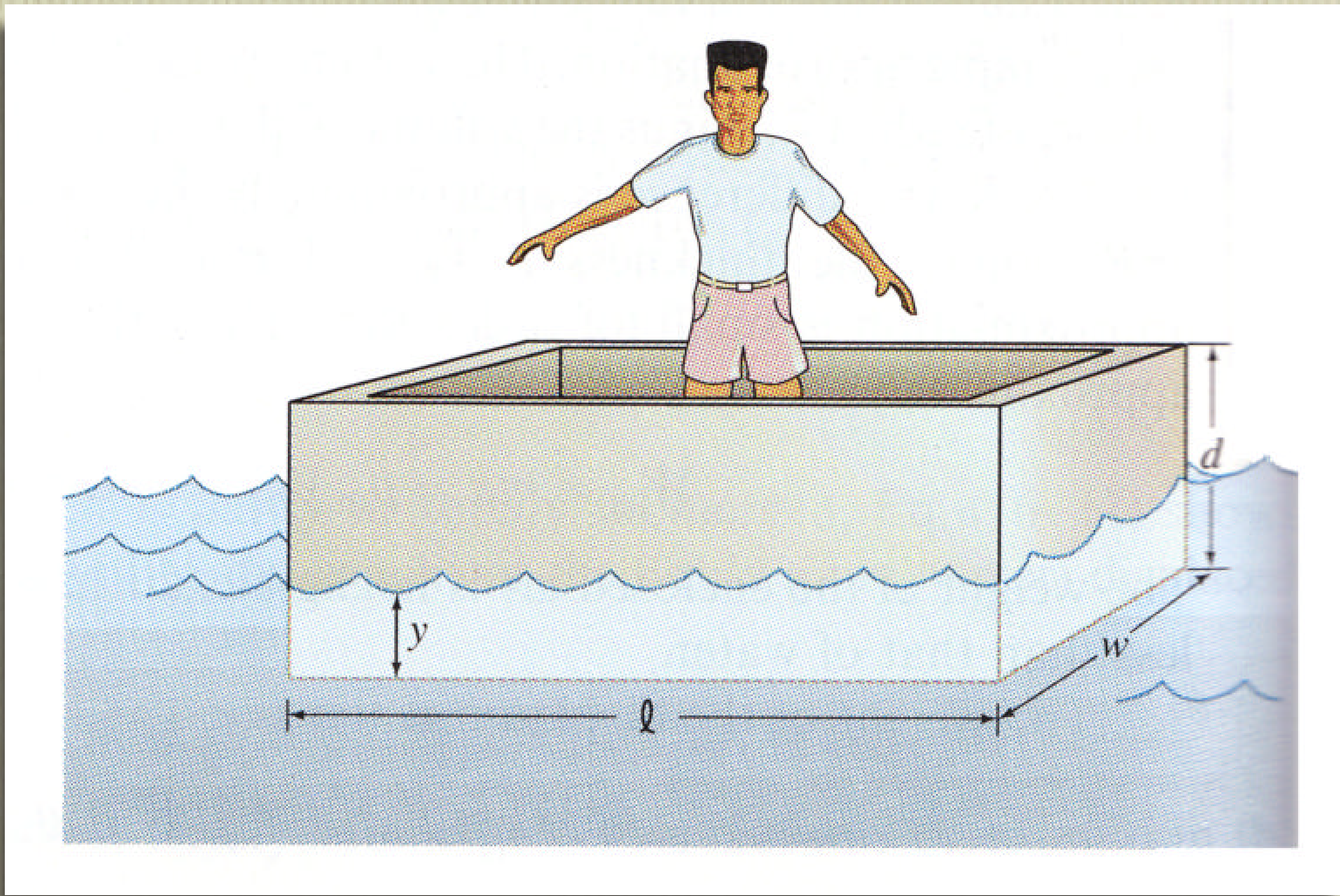
FIGURE 34.6 Sharon carries a charge past Bill.

Leisure time activities

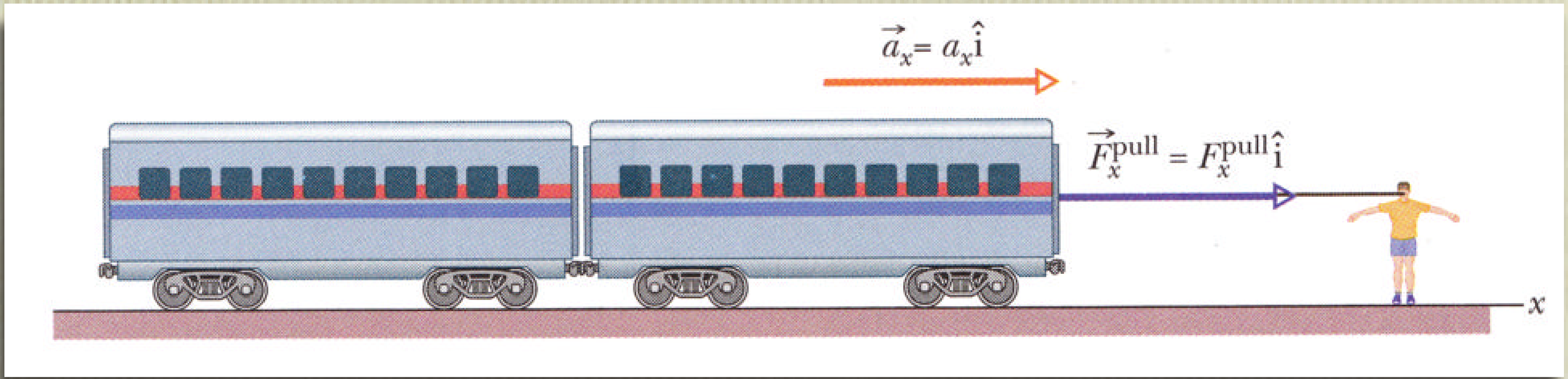
Leisure time activities



Leisure time activities

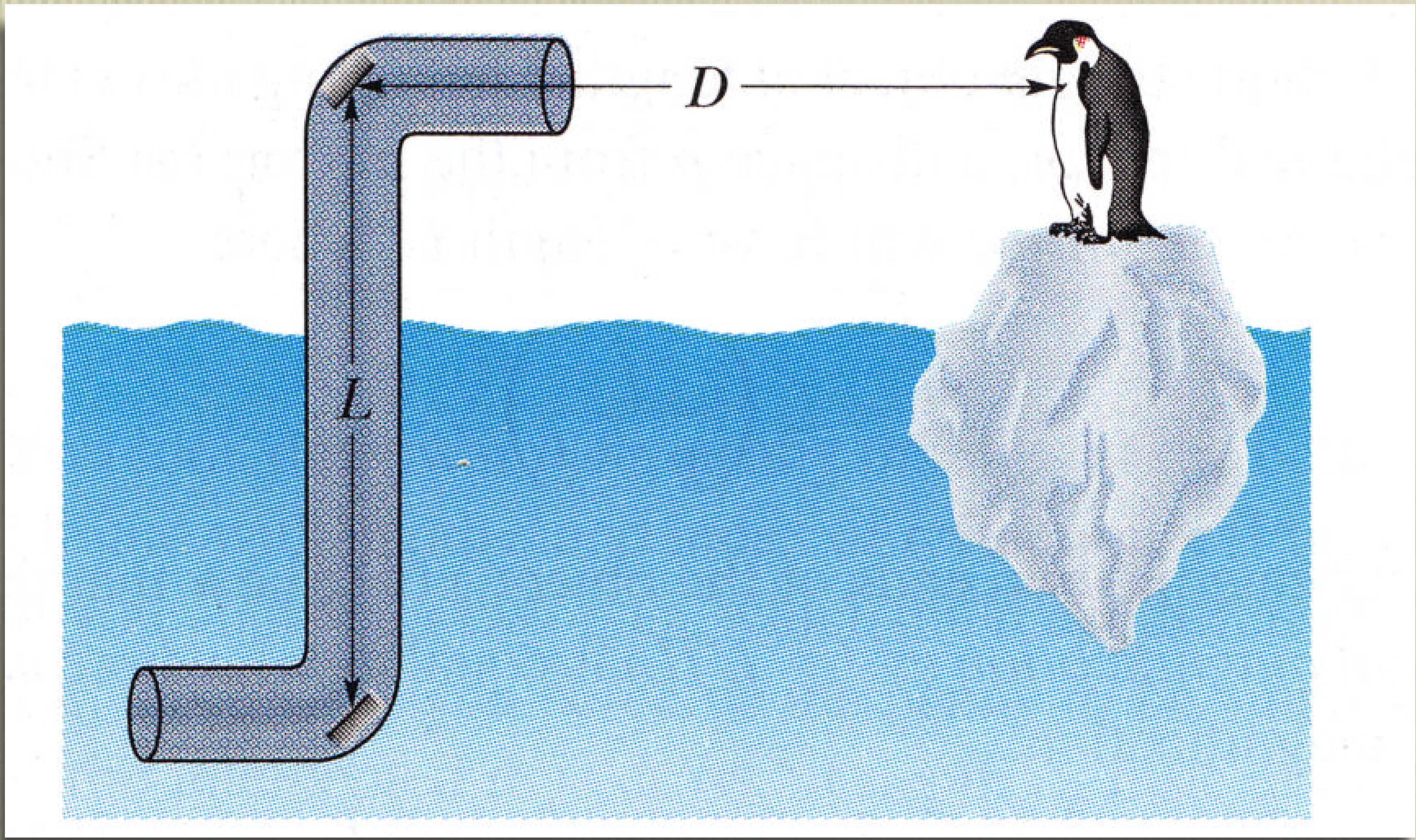


Leisure time activities

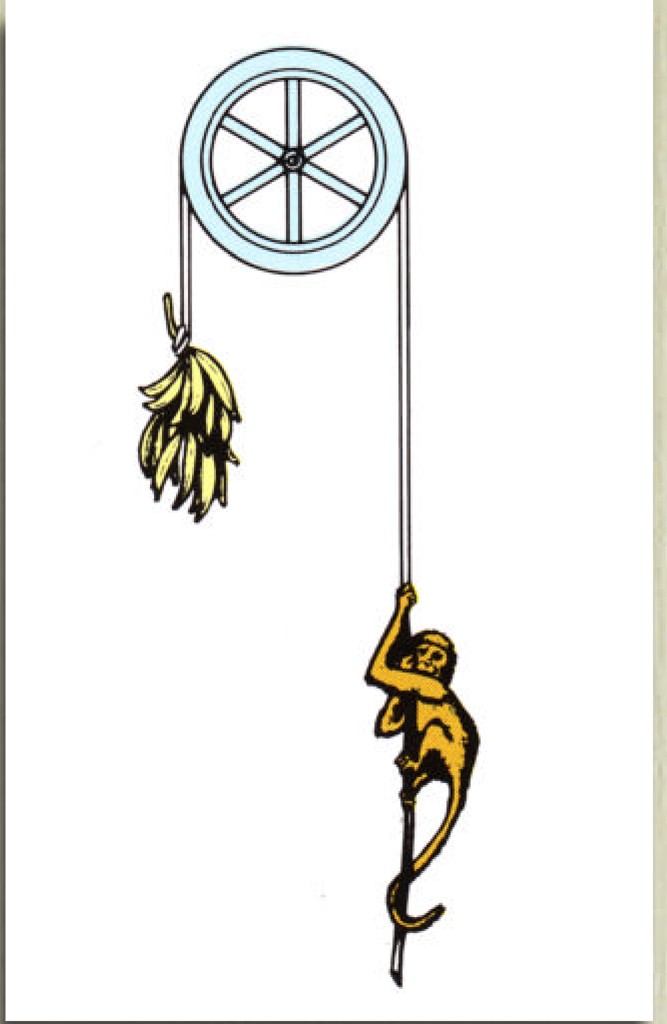


Fascinations

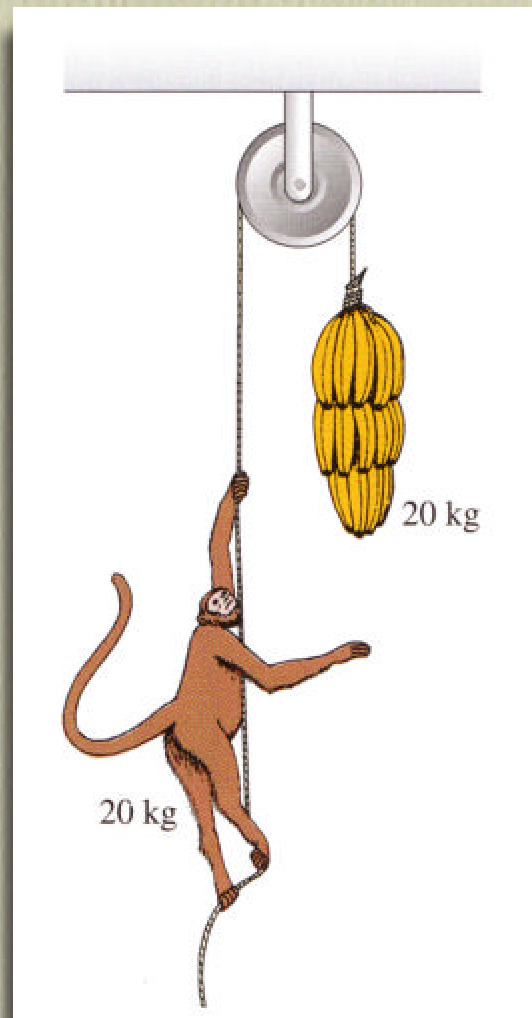
Fascinations



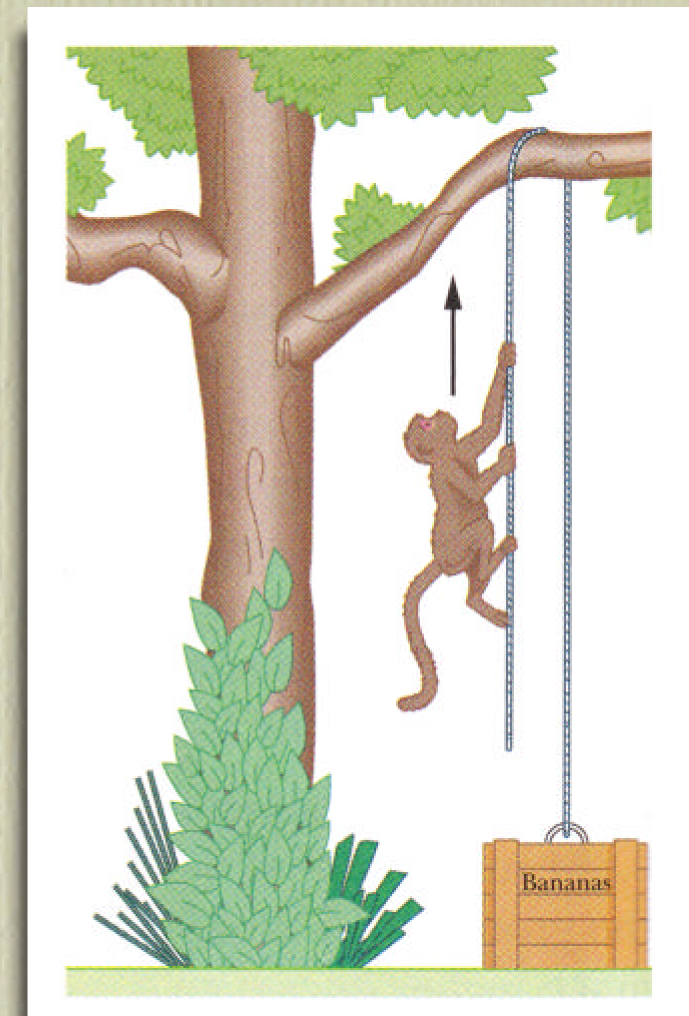
Fascinations



Fascinations



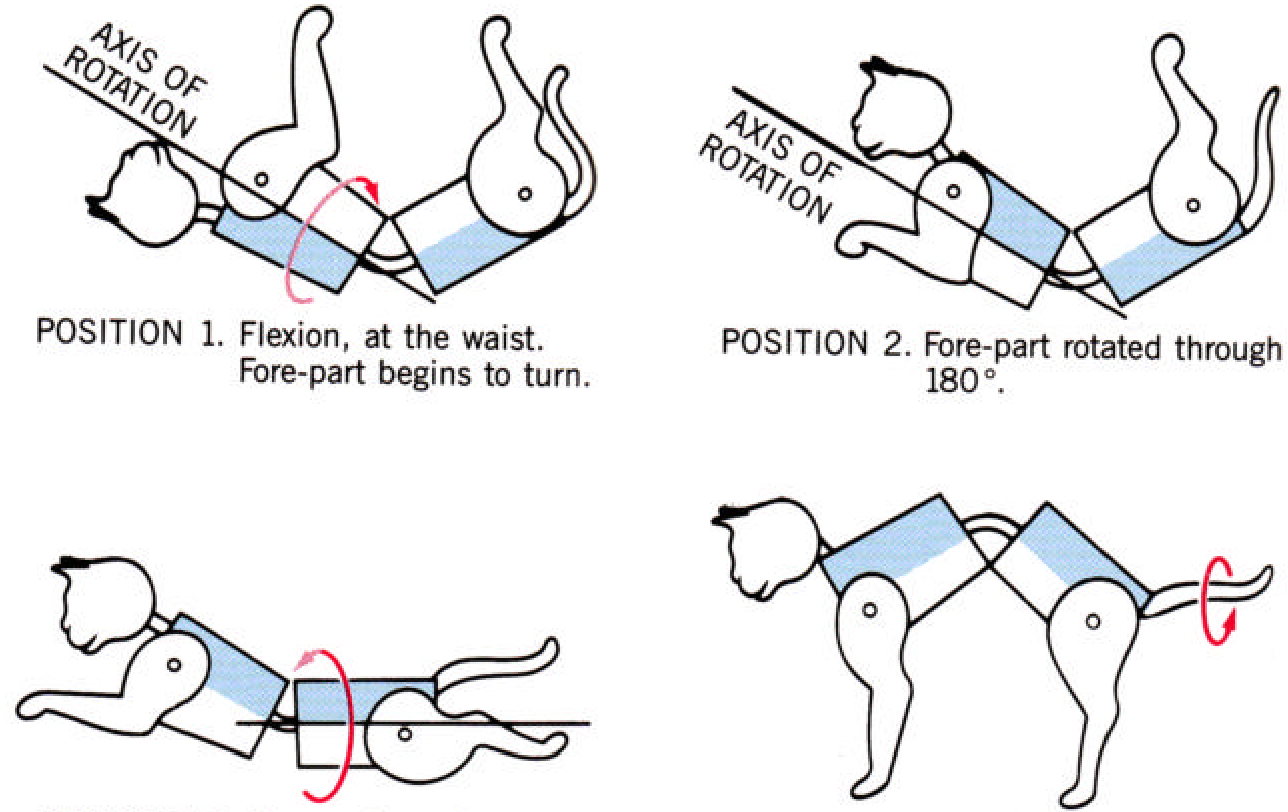
Fascinations



Fascinations

Spherical cows and...

Spherical cows and...



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

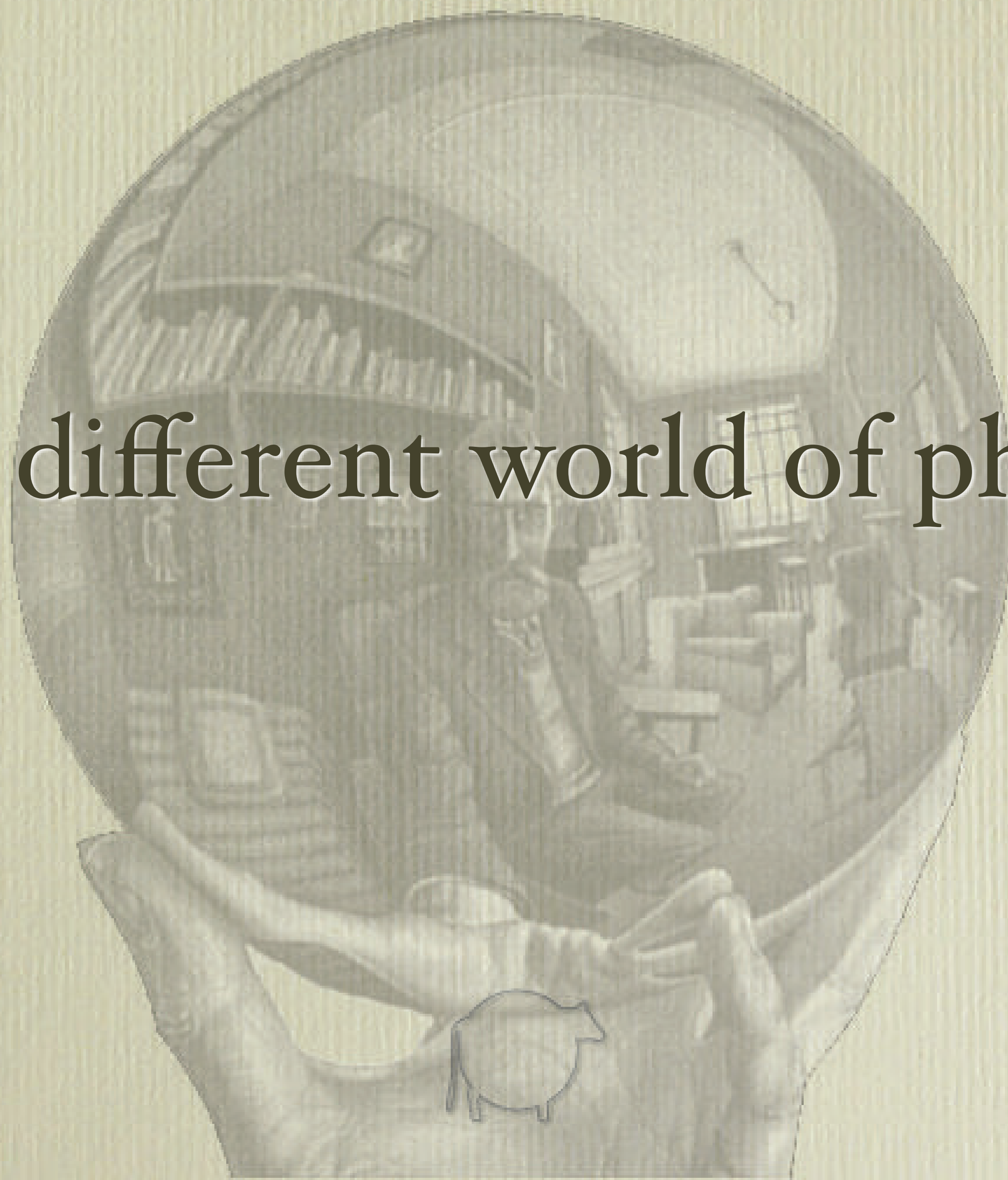
POSITION 2. Fore-part rotated through 180°.

POSITION 3. Rear end rotating on fore-end.

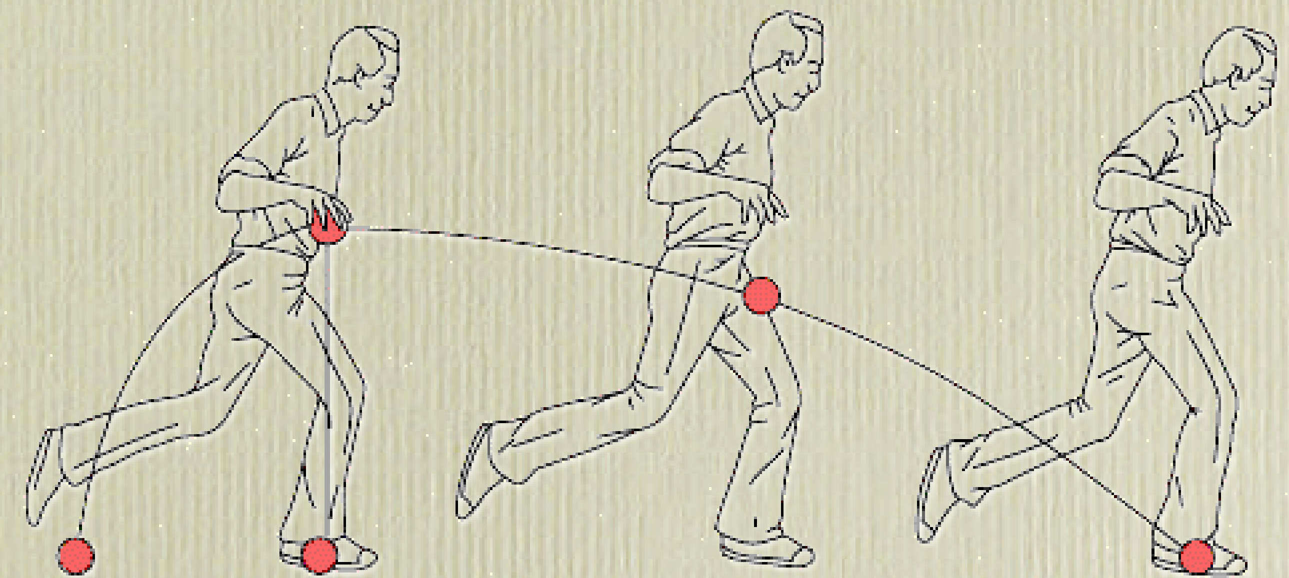
POSITION 4. Back arched. Legs extended for landing. Tail circling for ''trim.''

Silly art makes us look weird

The different world of physics

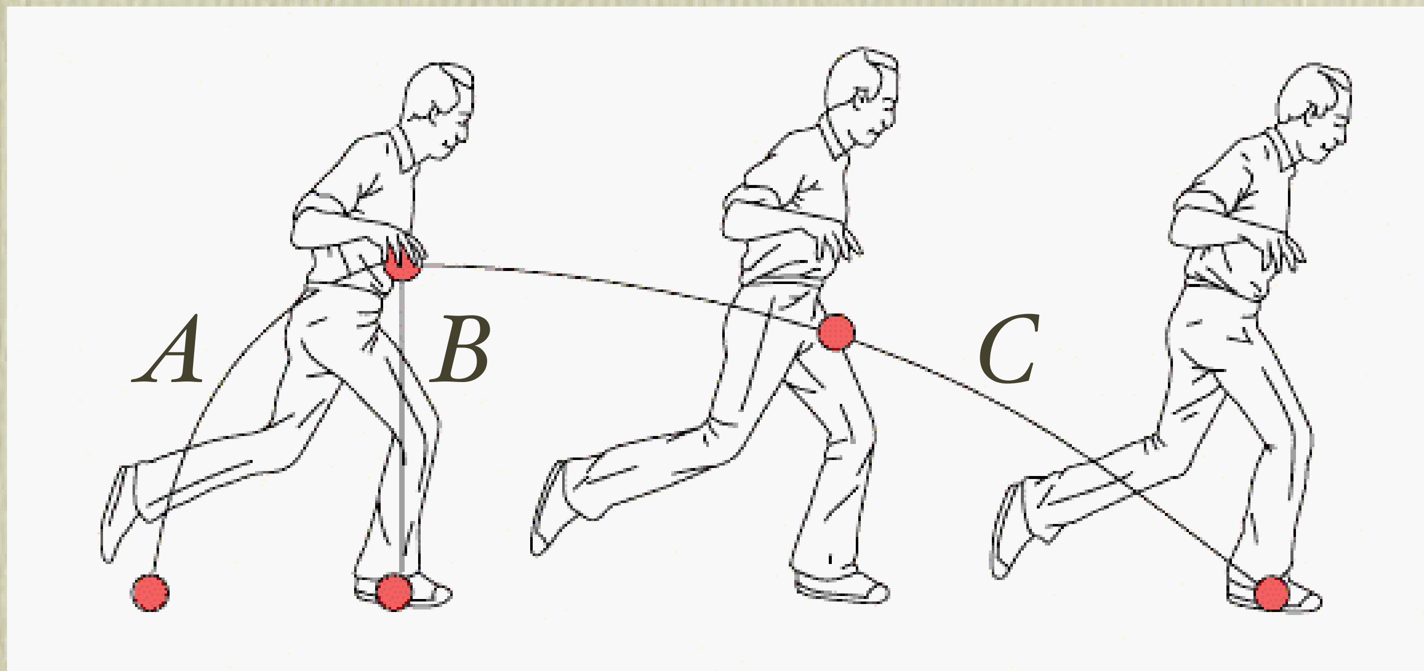


Parabolic motion

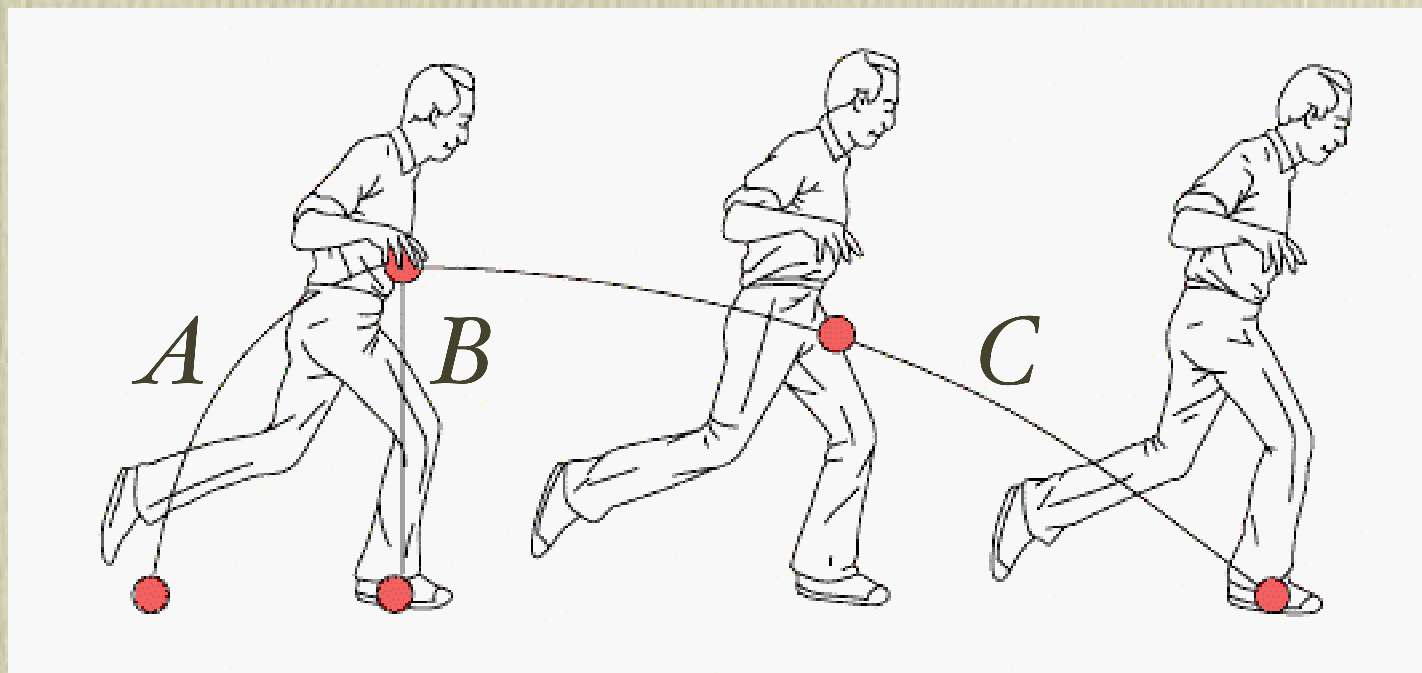


M. McCloskey, *Intuitive Physics*
Scientific American 248 (1983), pp. 122-130

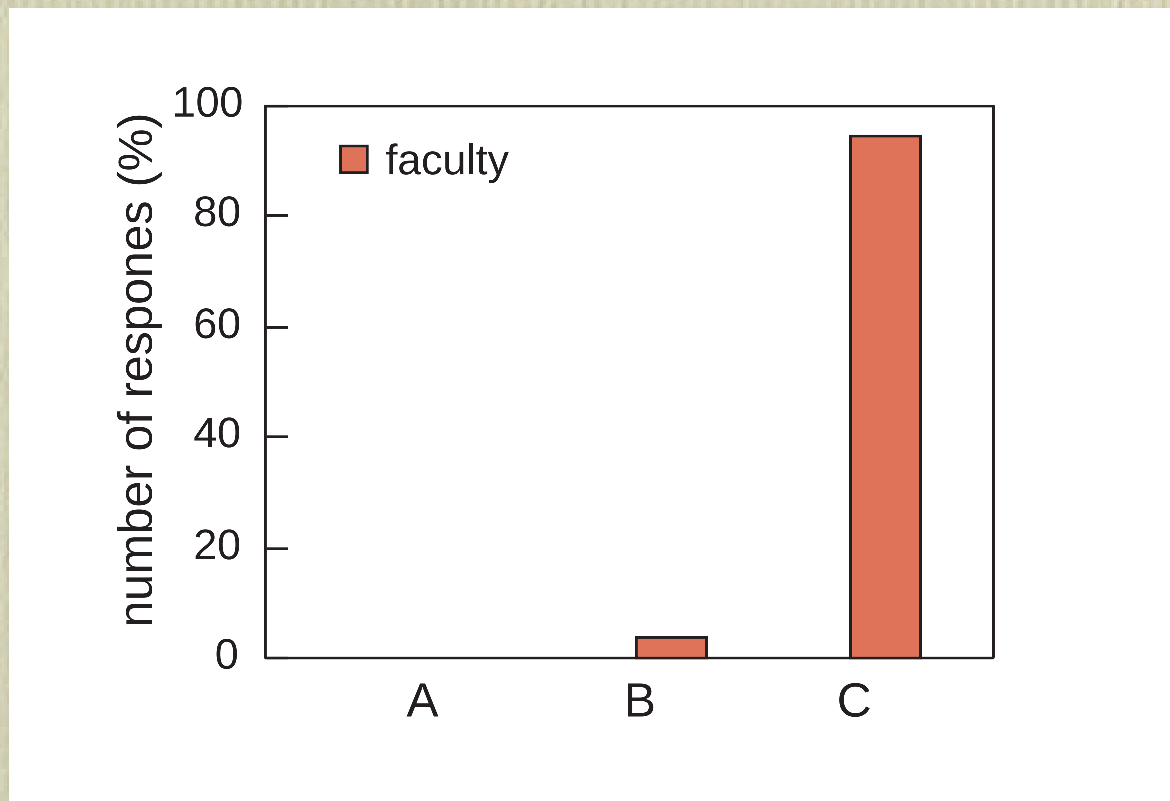
Which of the three paths shown (*A*–*C*) most closely resembles the path taken by the ball?



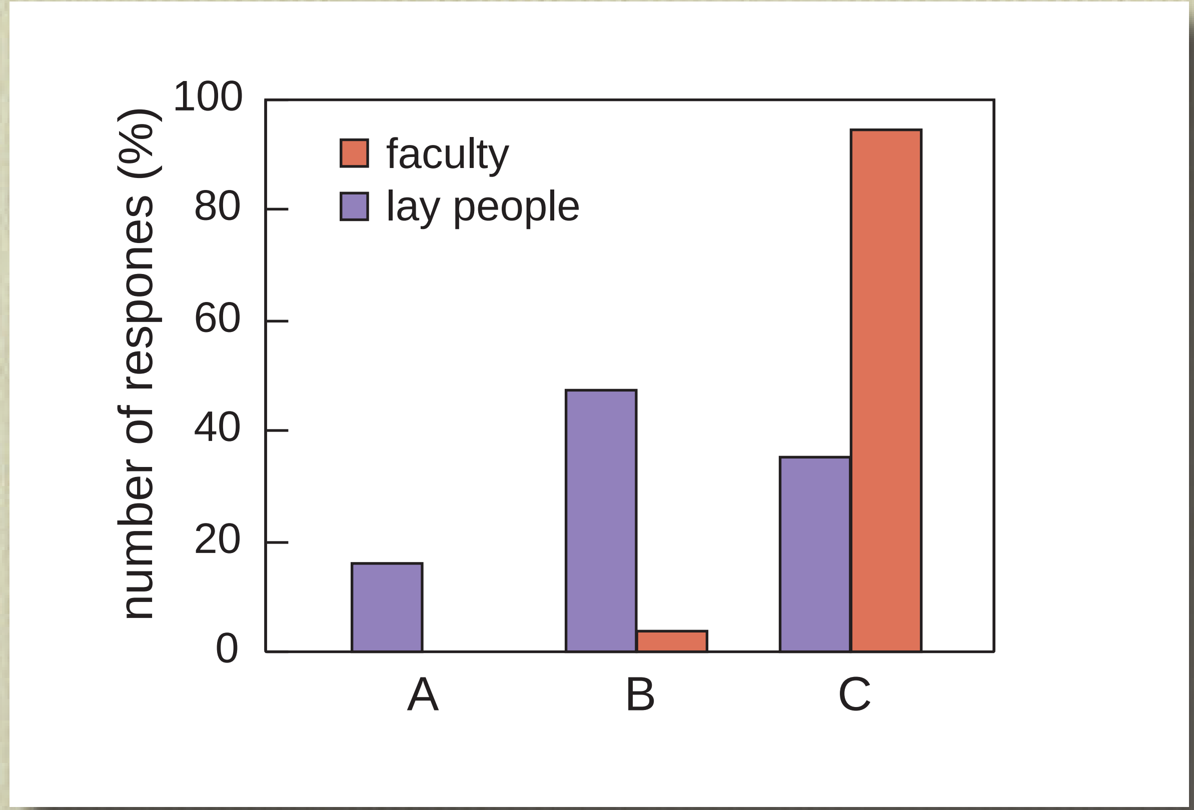
Which trajectory does the lay person select?



Predictions



Predictions



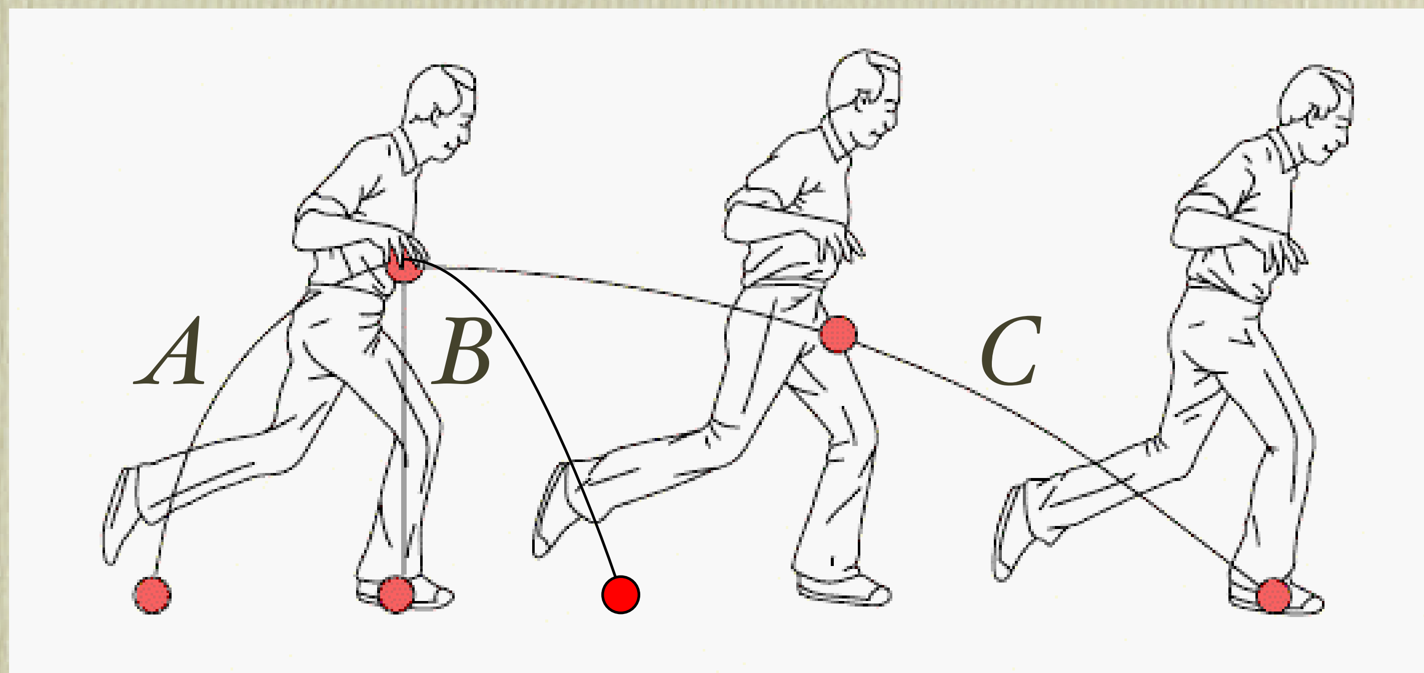
“The ball can’t go that far forward.”

"My eyes can't lie; I've seen B."

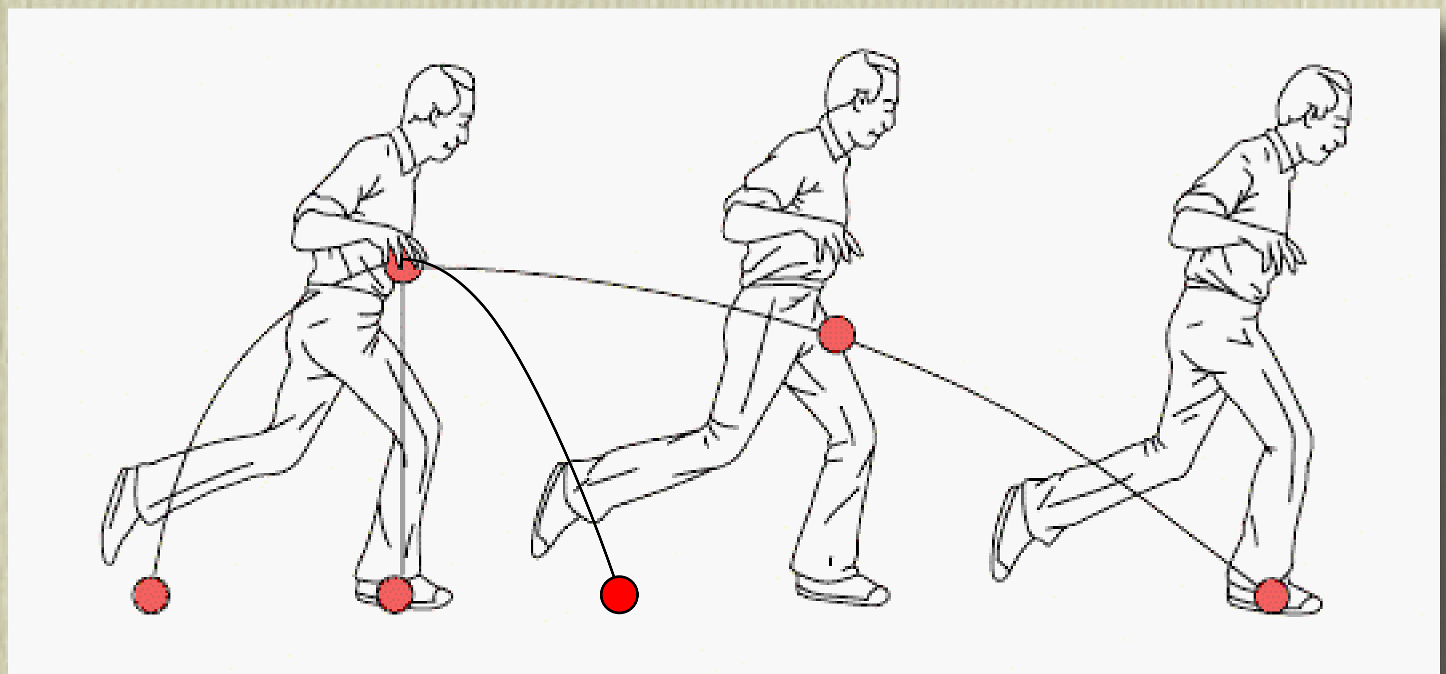
"I'd like to see it."

“Give me a proof.”

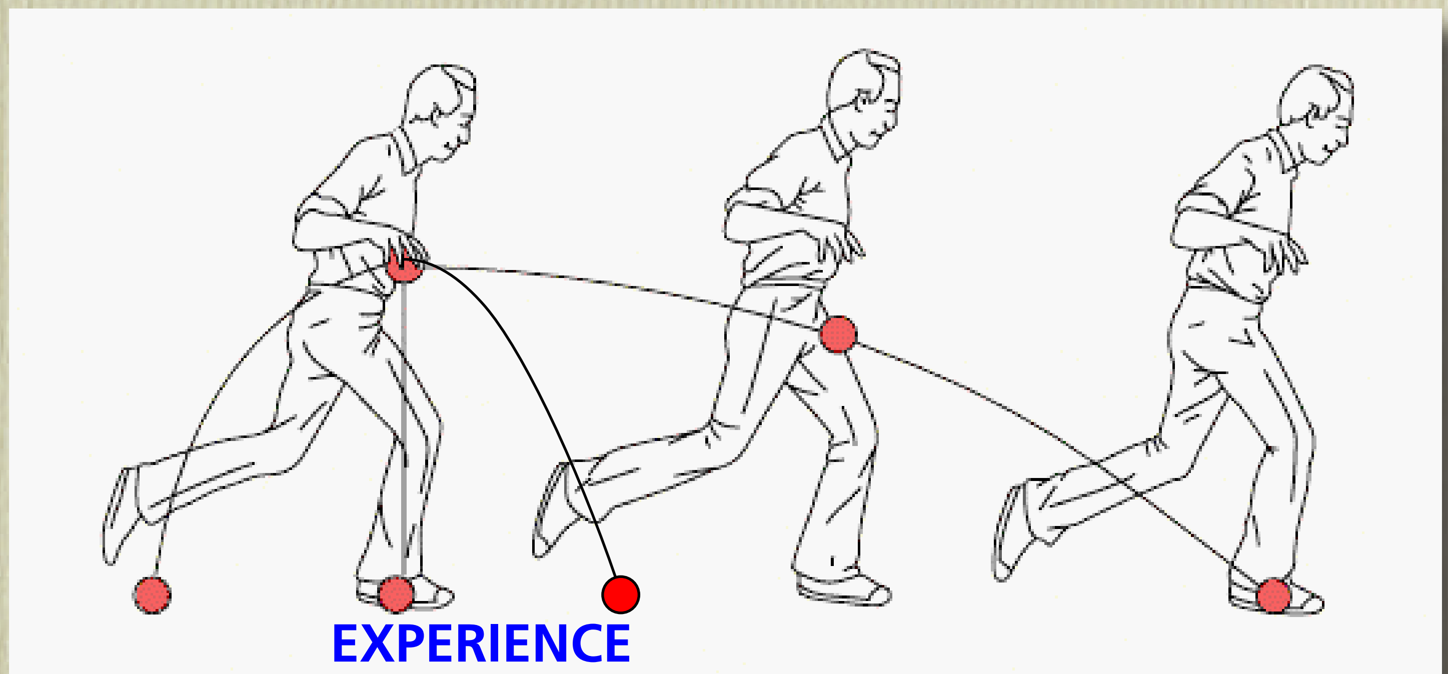
B is closest!



The lay person

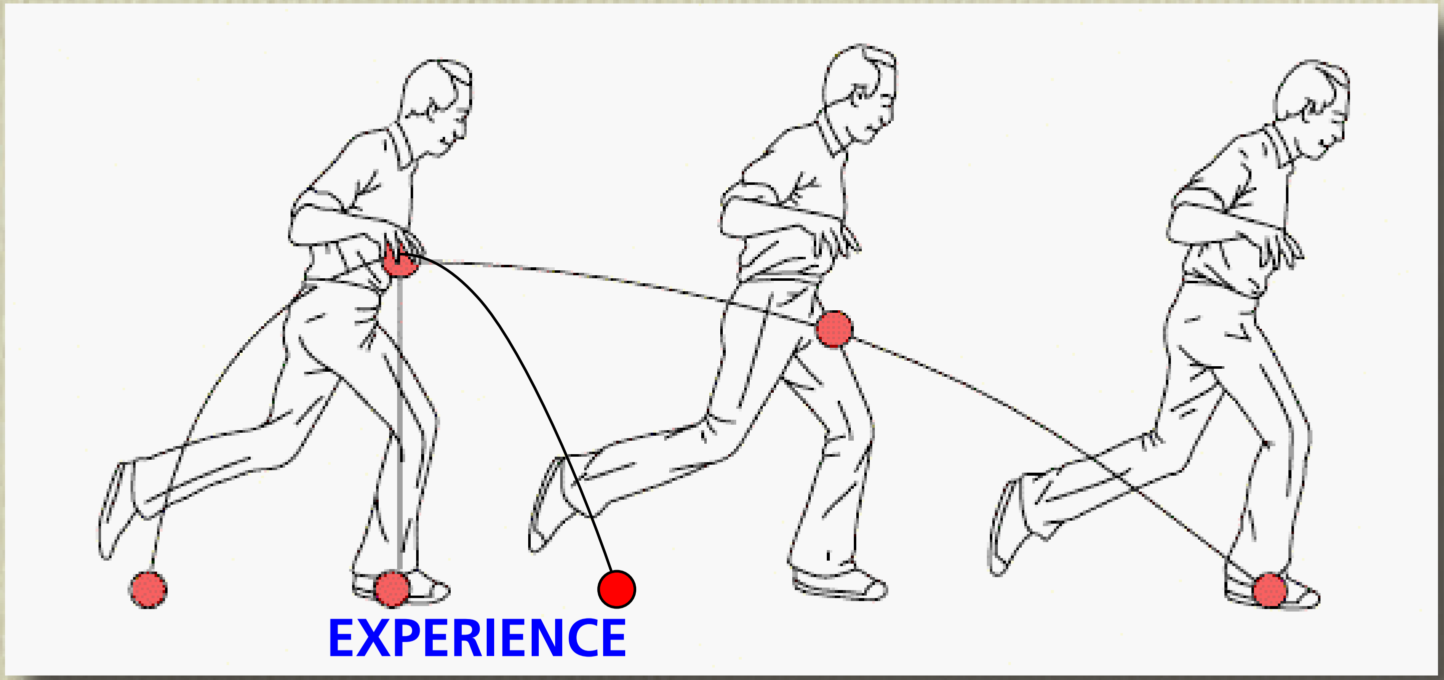


The lay person

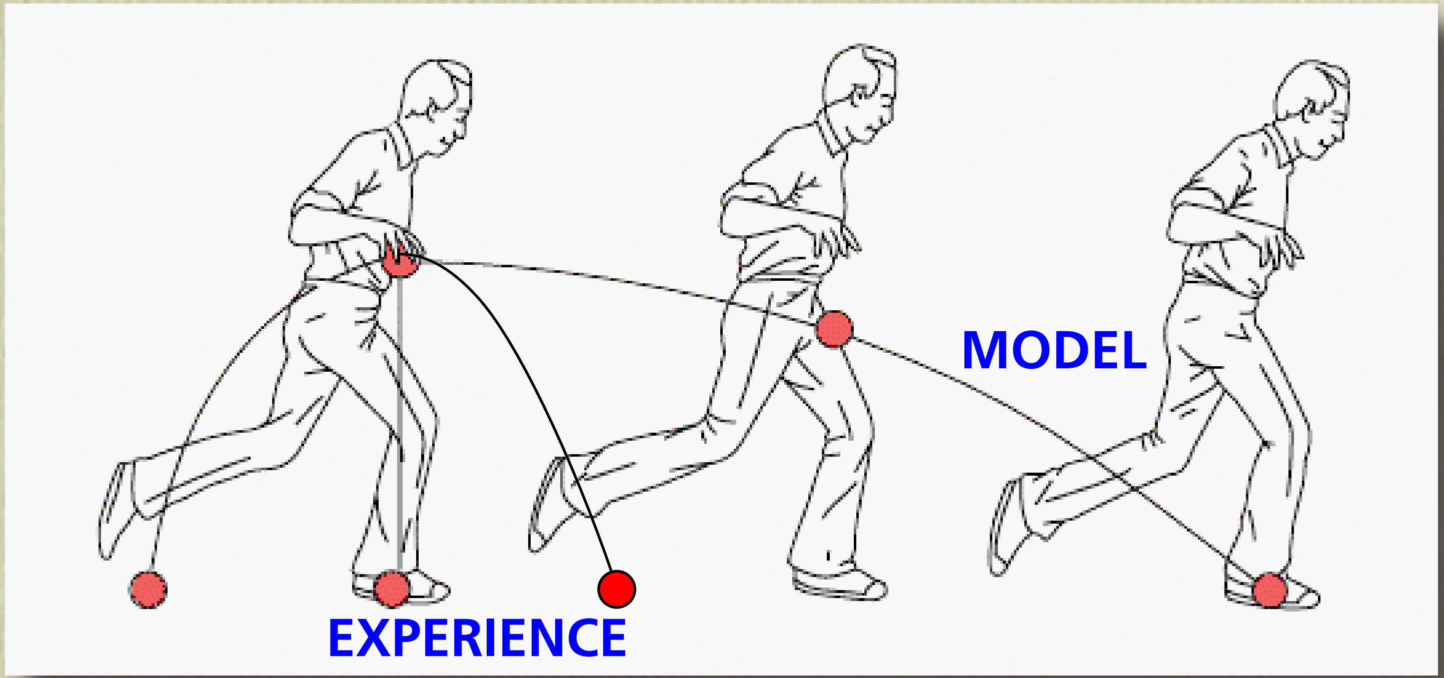


Choice dictated by experience

The physicist

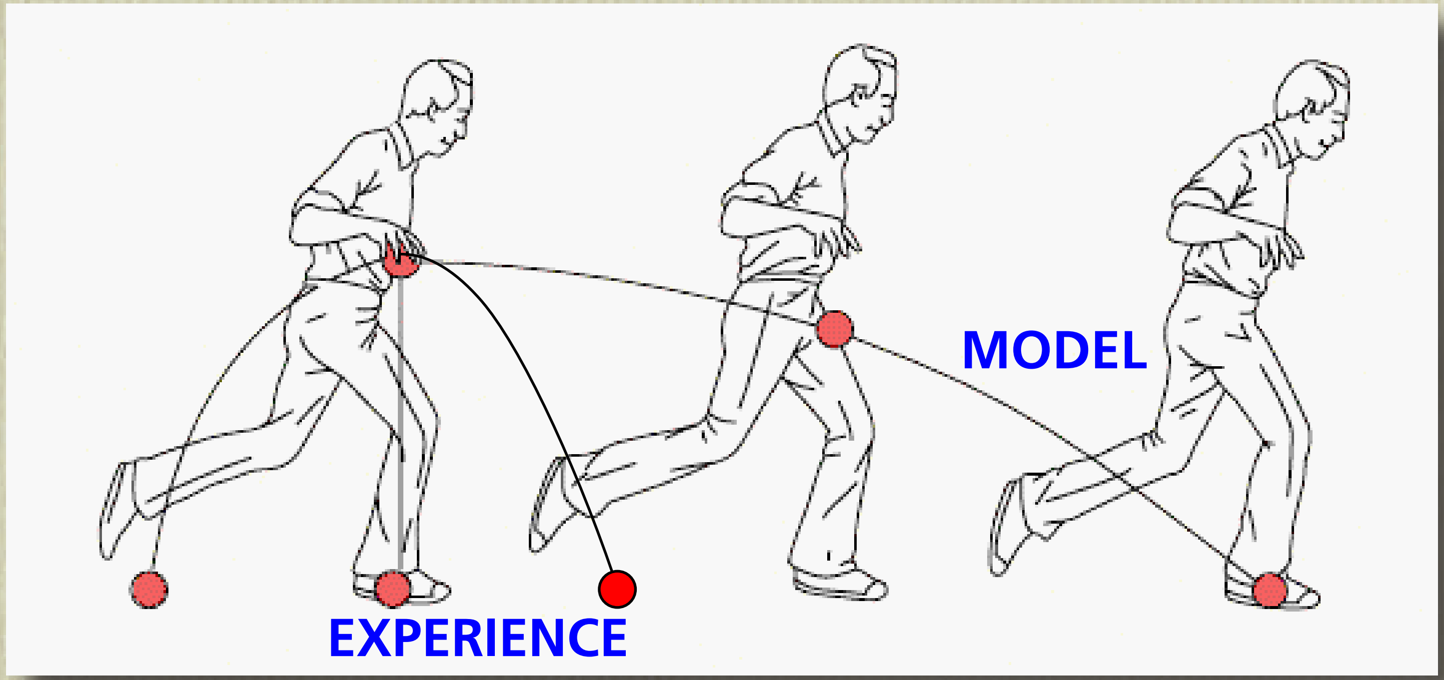


The physicist



Choice dictated by the model...

The physicist



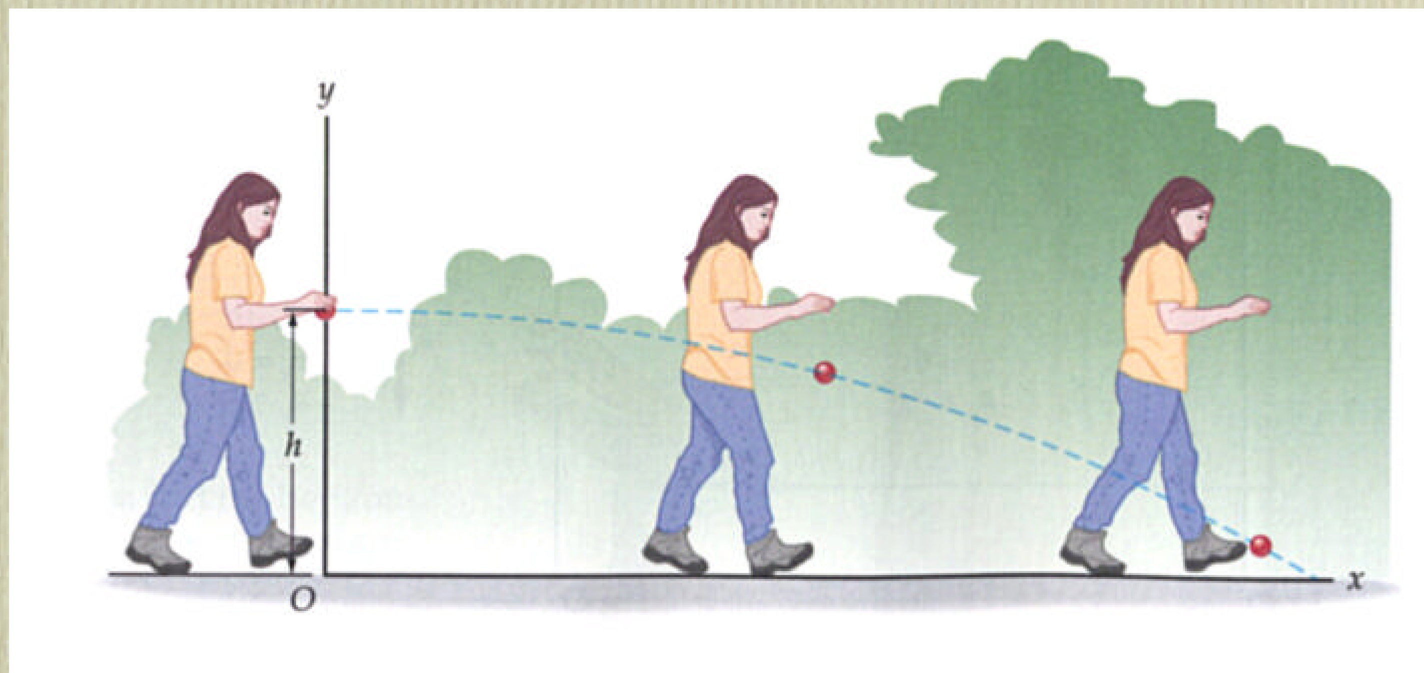
...even if representation of model is *wrong*

“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.”

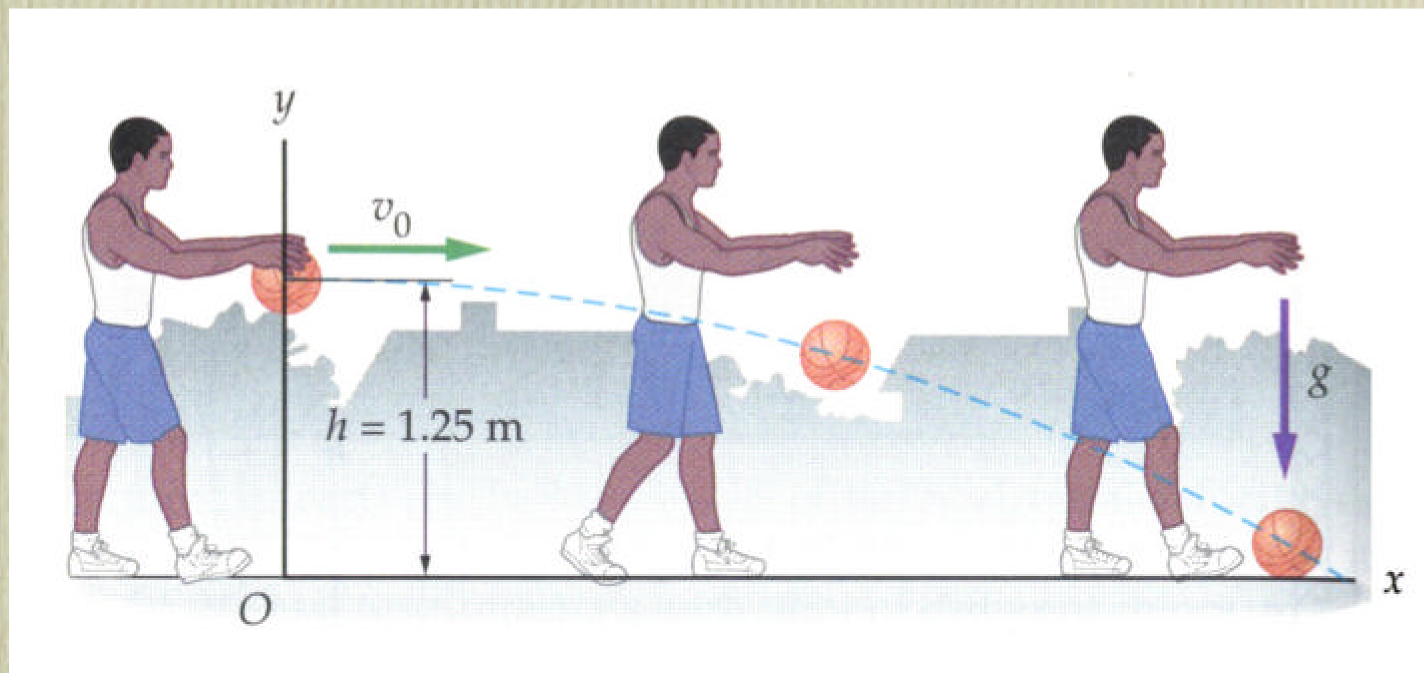
Model overrides experience

What do our students see?

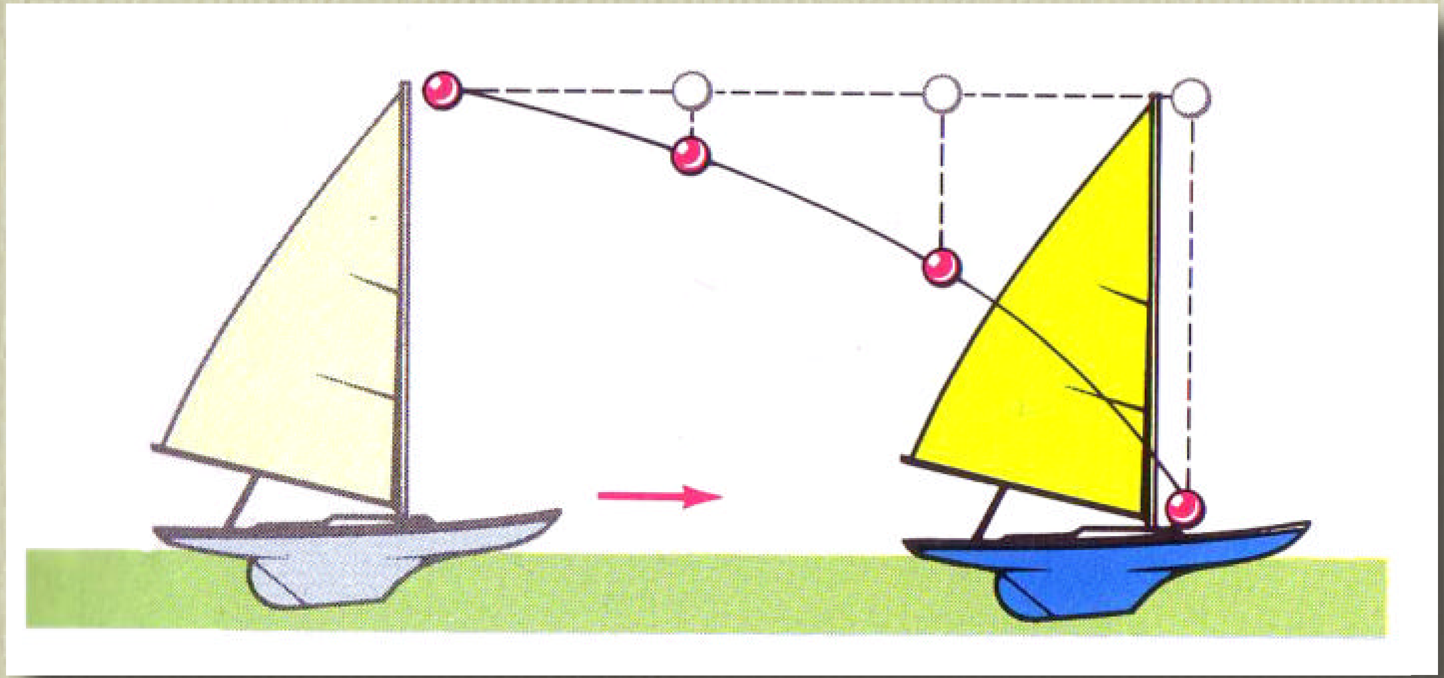
Microgravity



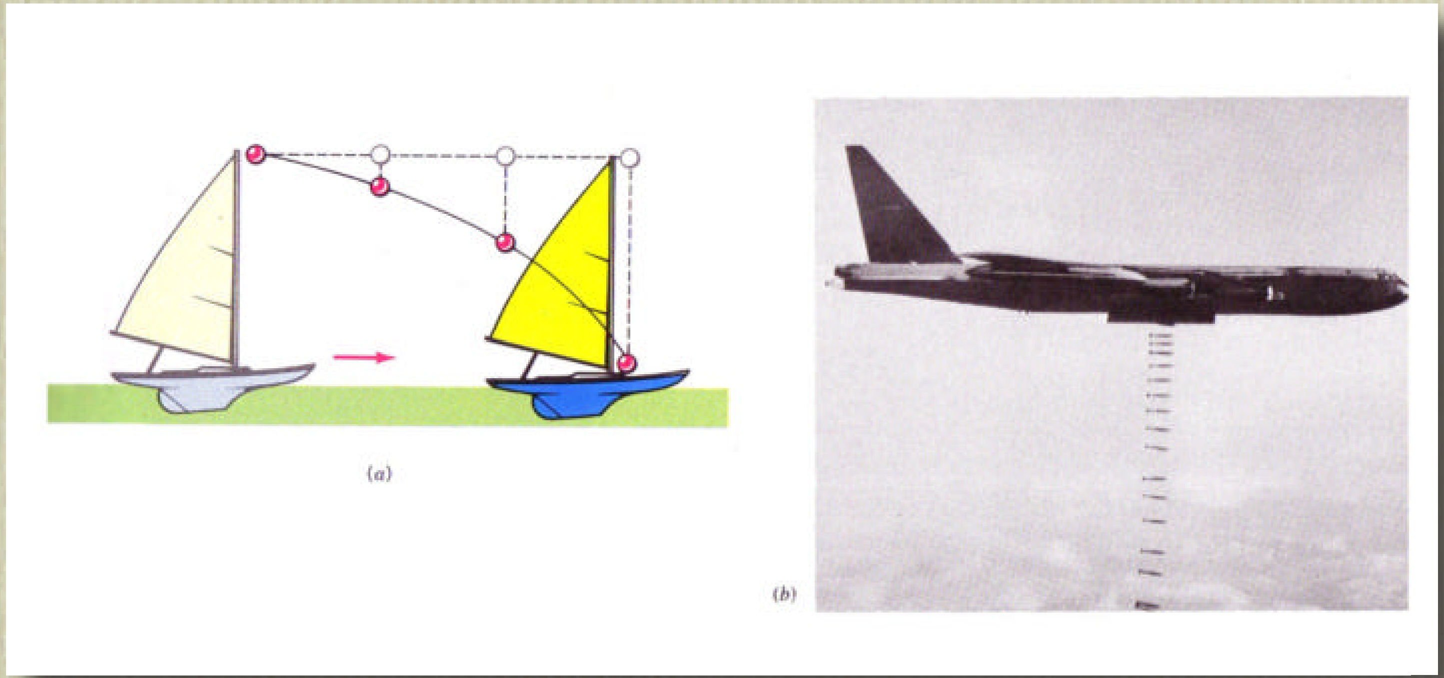
Micrograviity



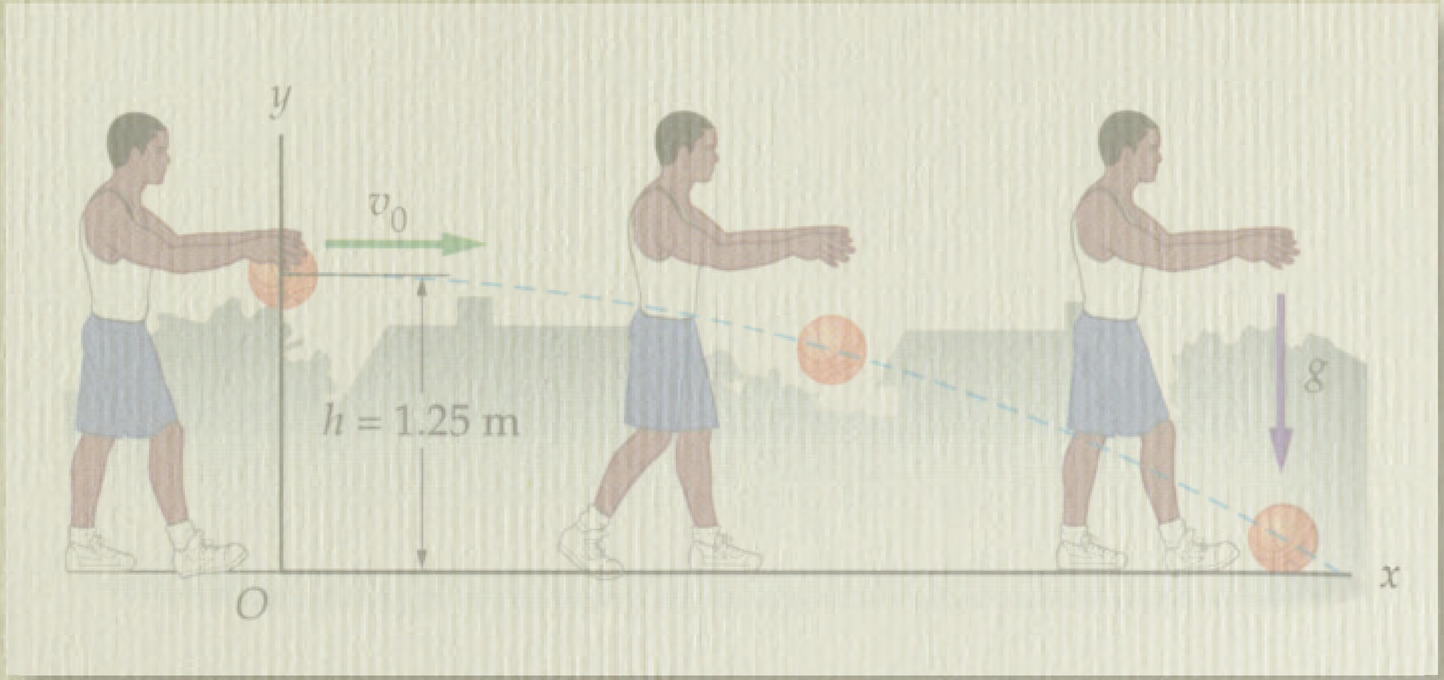
Microgravity



Microgravity

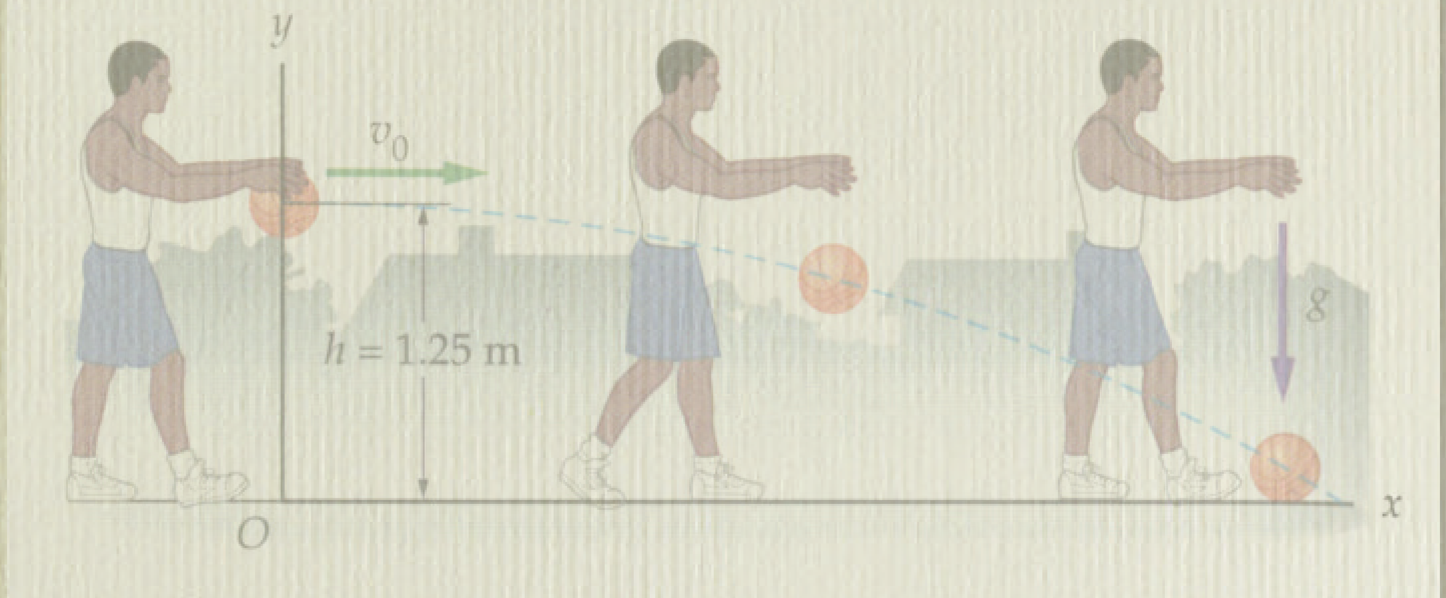


Microgravity



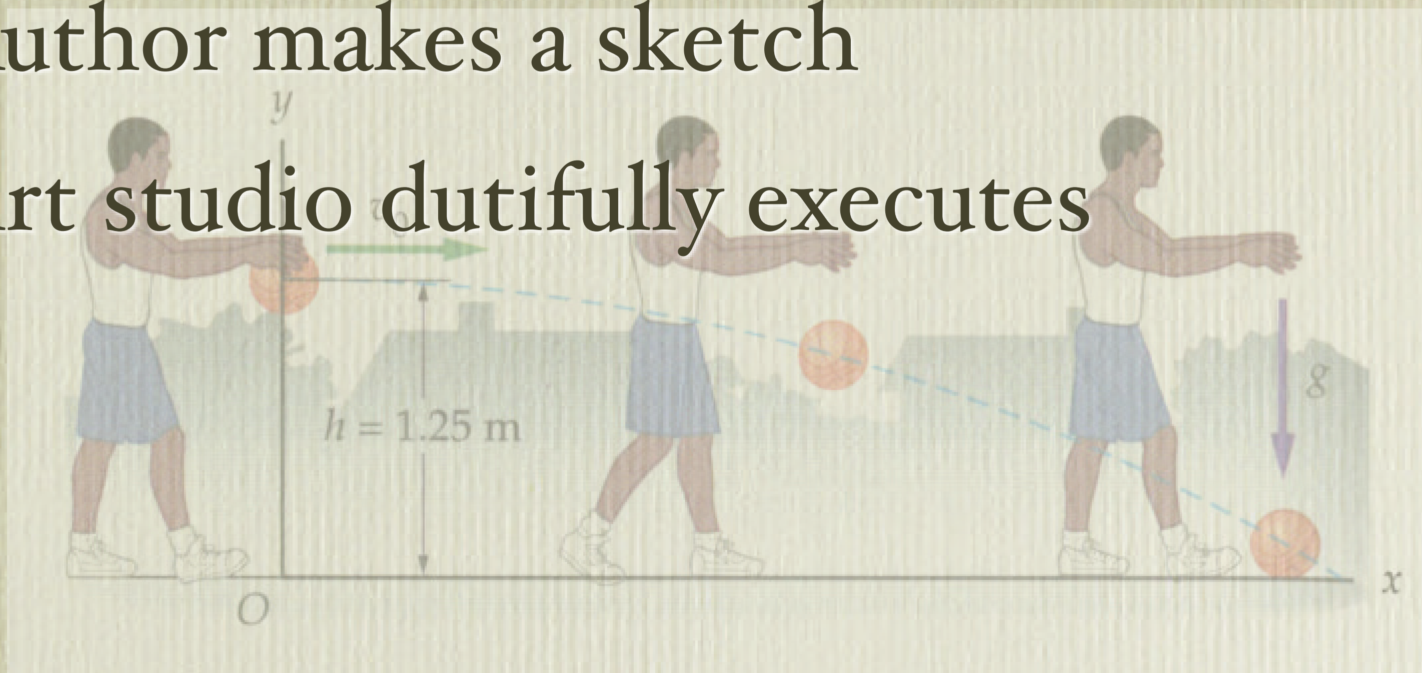
Micrograrity

- Author makes a sketch



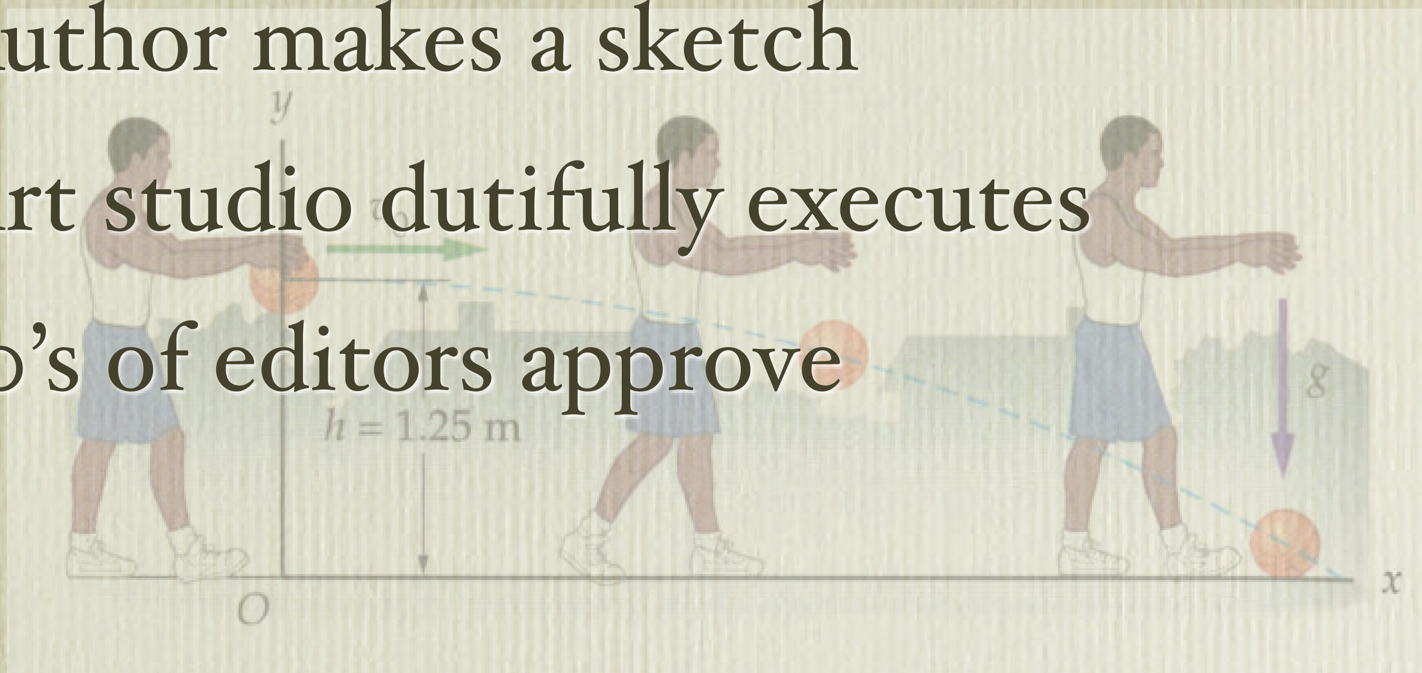
Micrograviity

- Author makes a sketch
- Art studio dutifully executes



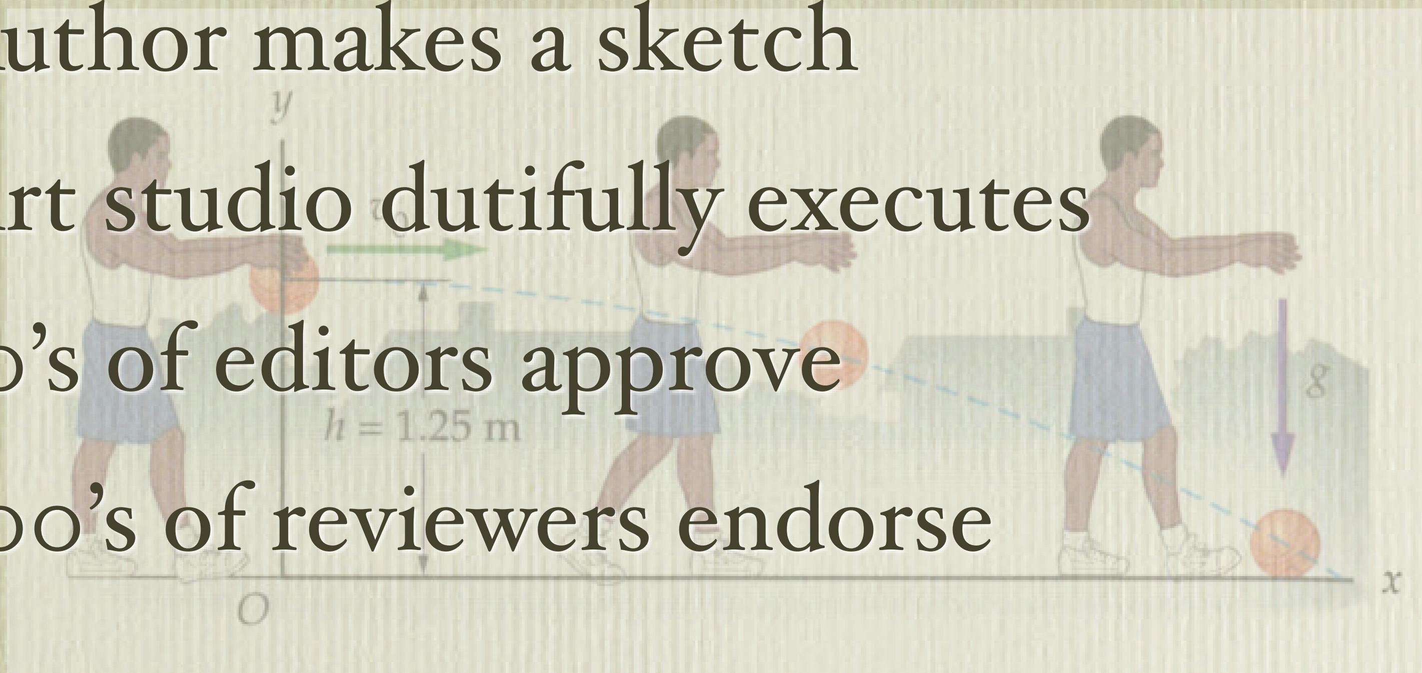
Microgravity

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



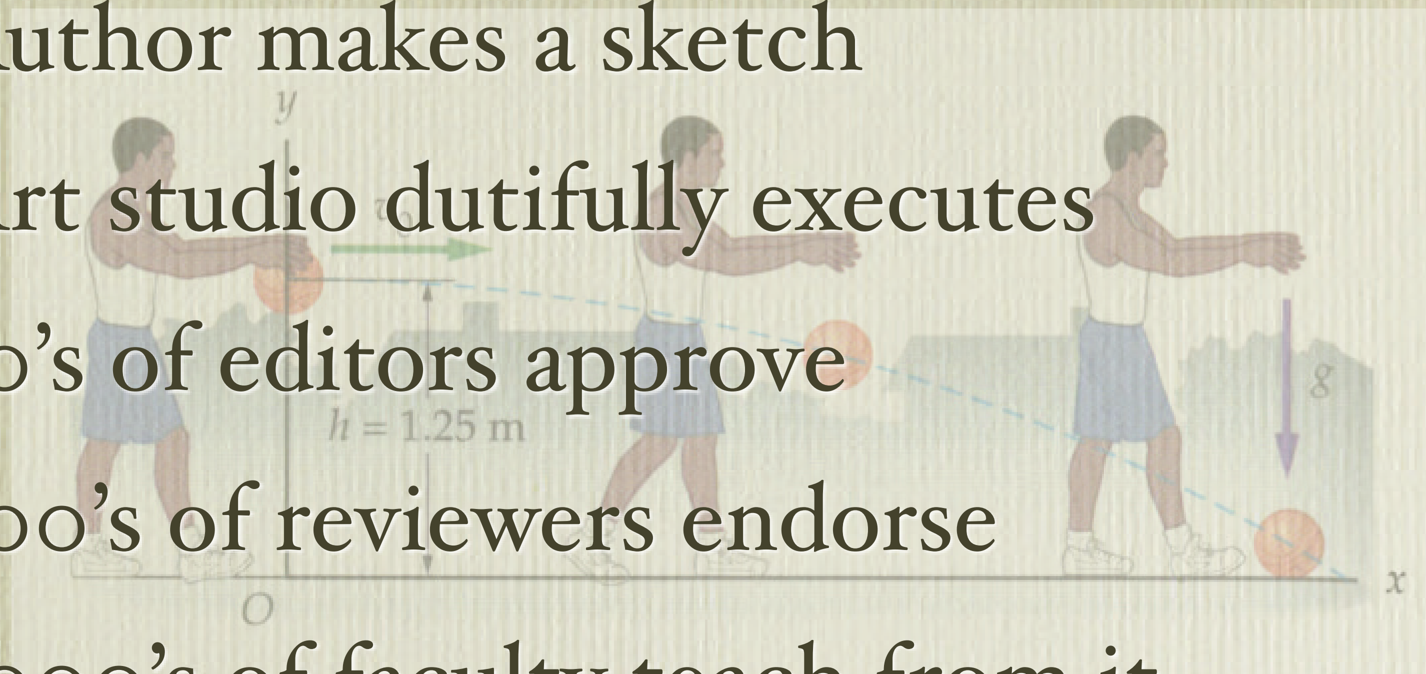
Microgravity

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



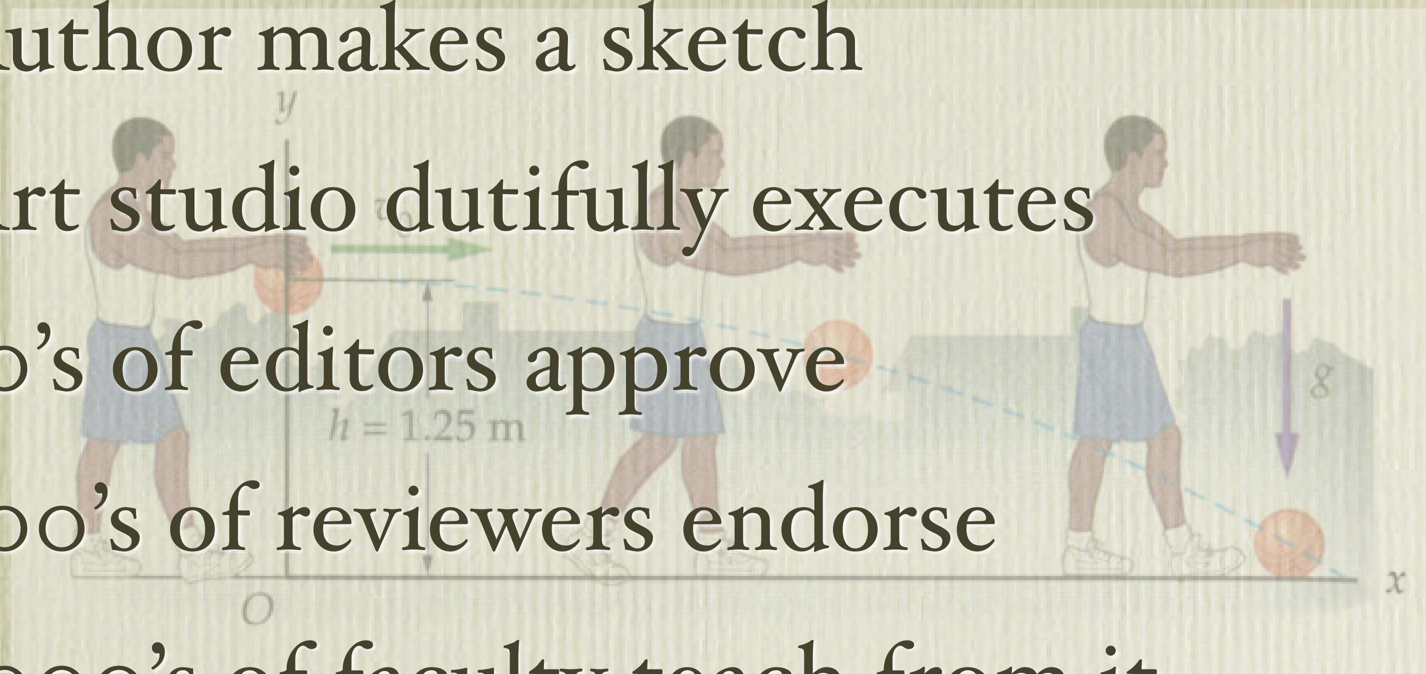
Microgravity

- 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

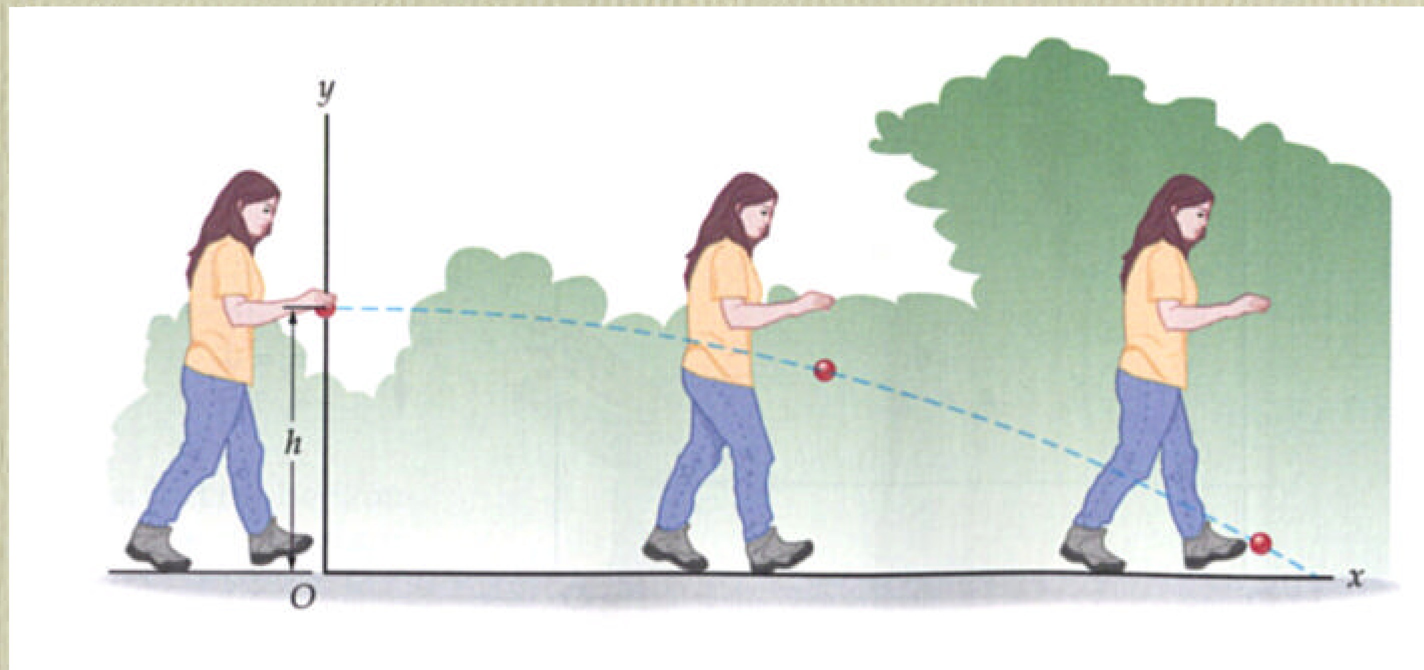
- Author makes a sketch
- Art studio dutifully executes
- 10's of editors approve
- 100's of reviewers endorse
- 1000's of faculty teach from it
- 10,000's of students grudgingly regurgitate



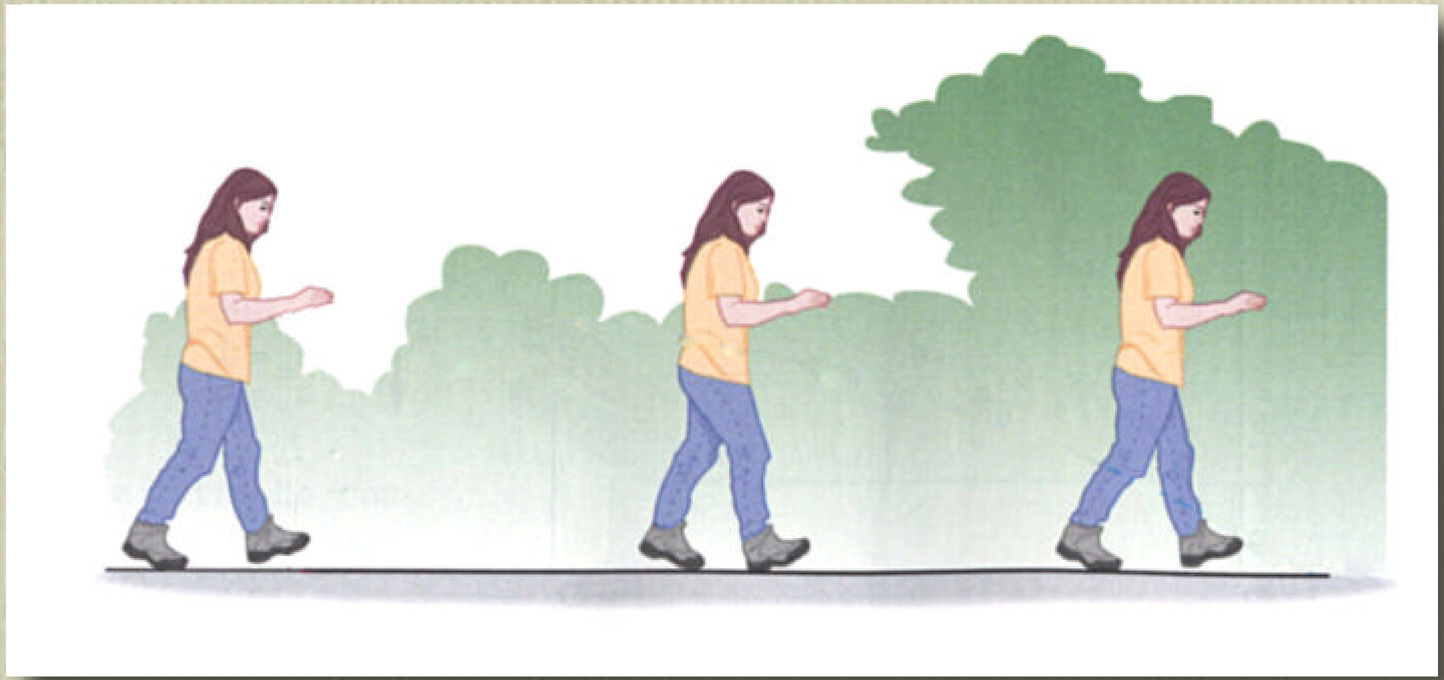
Physics is...

"almost on a totally different plane of existence."

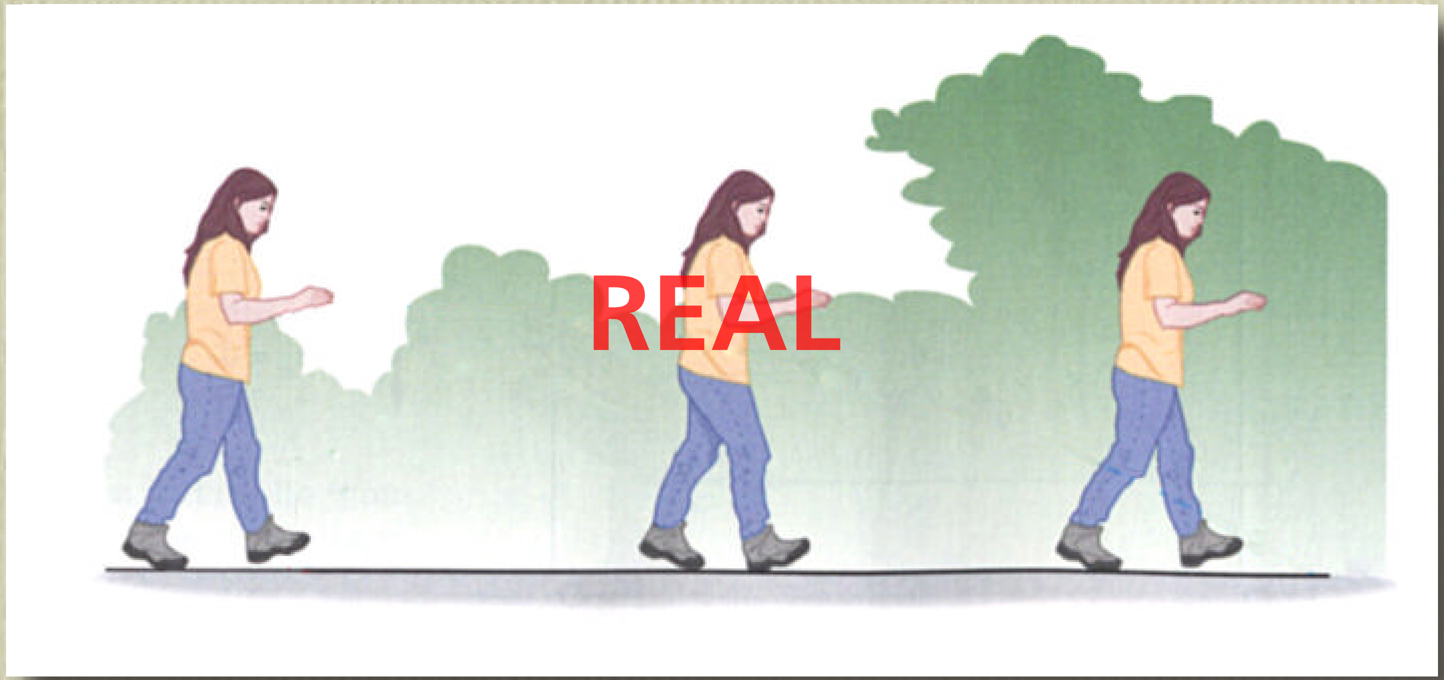
Realism



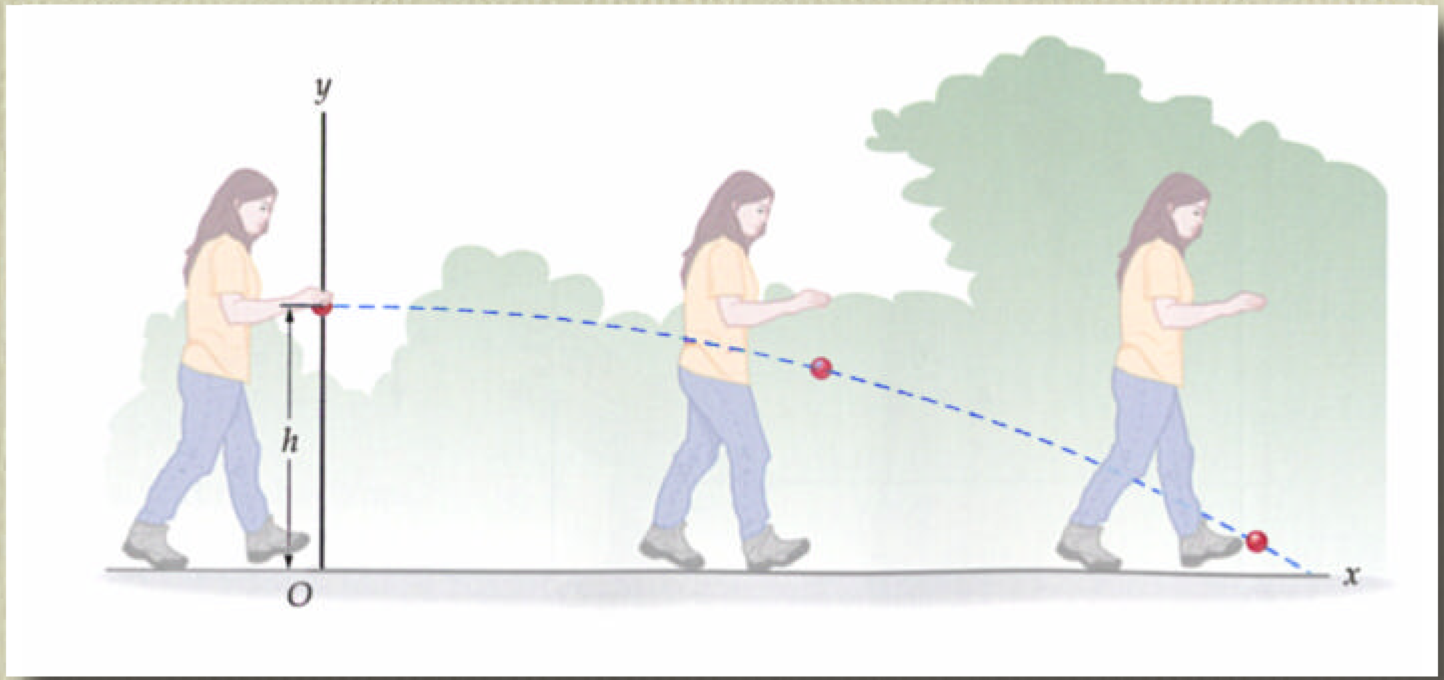
Realism



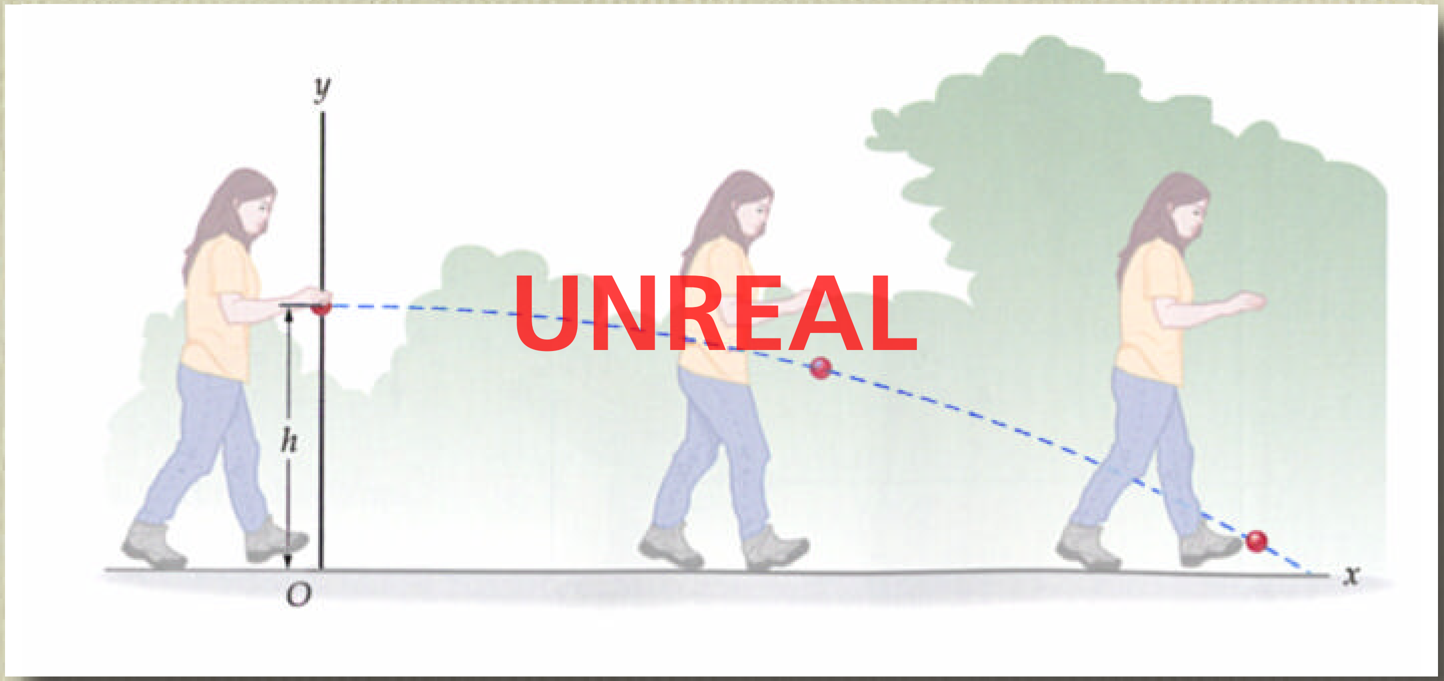
Realism



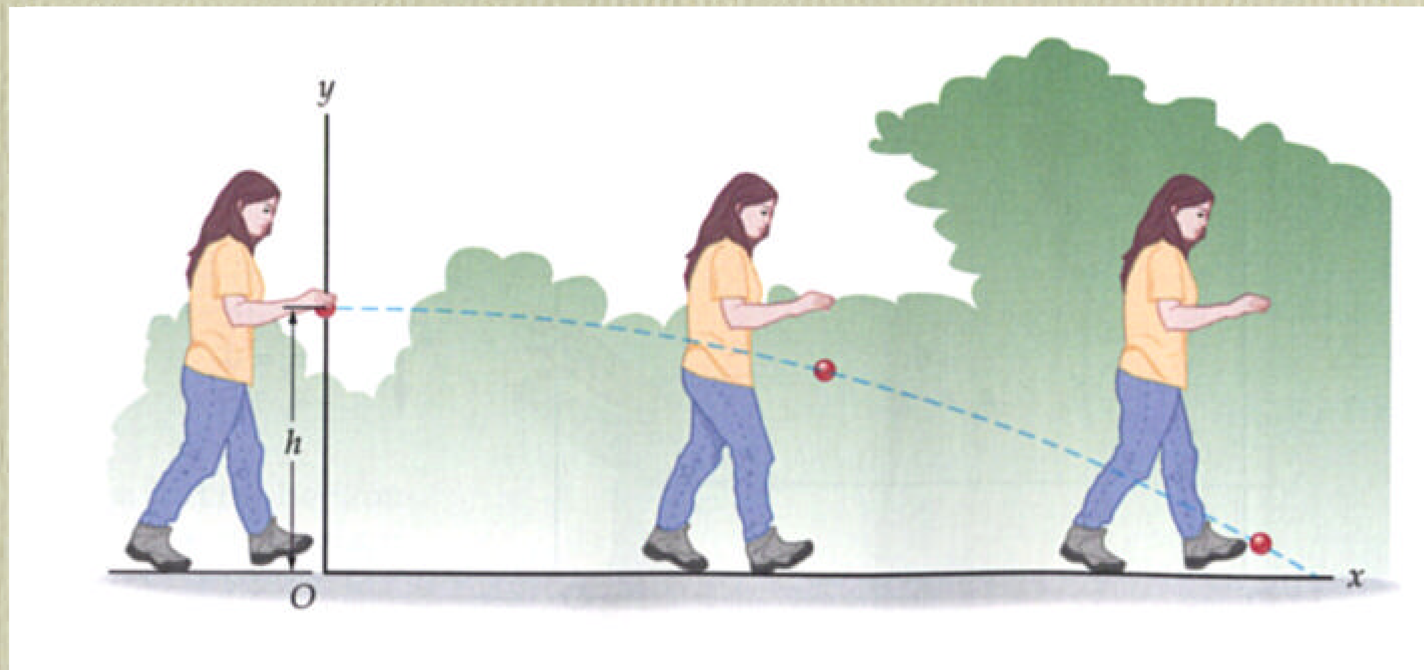
Realism



Realism

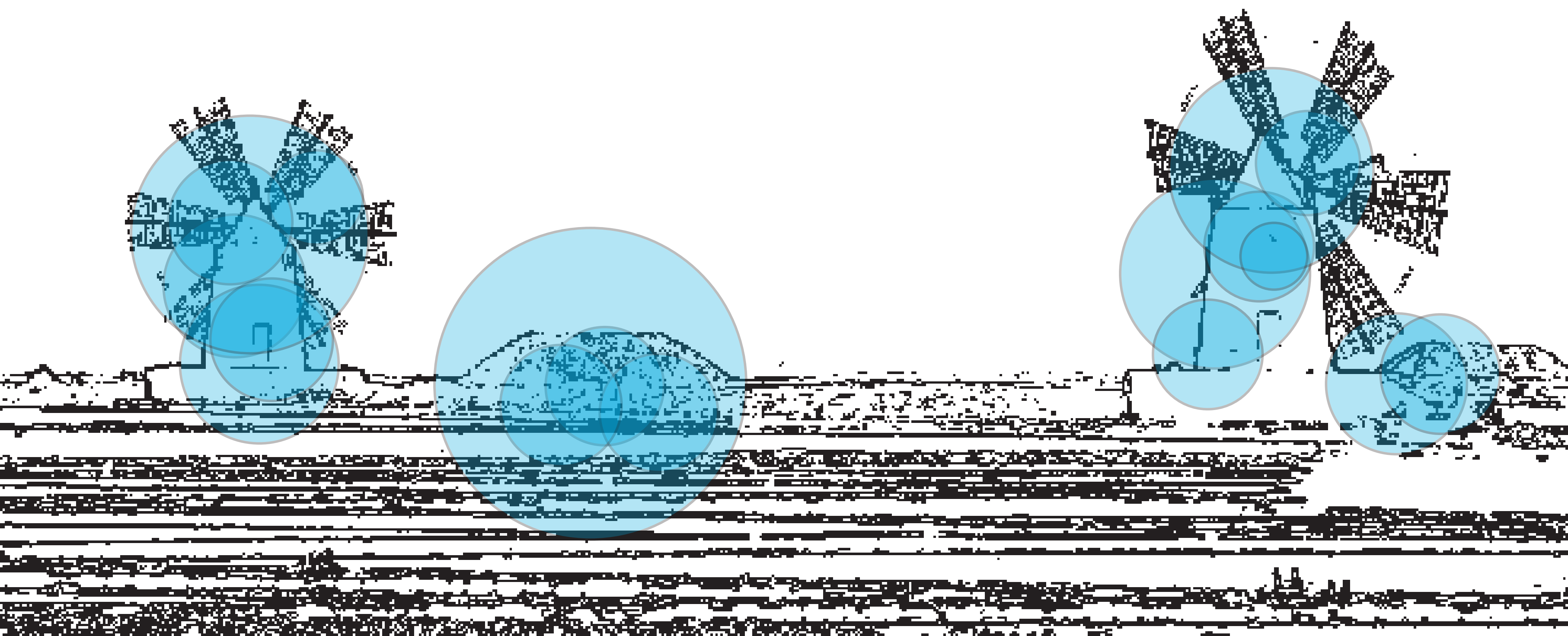


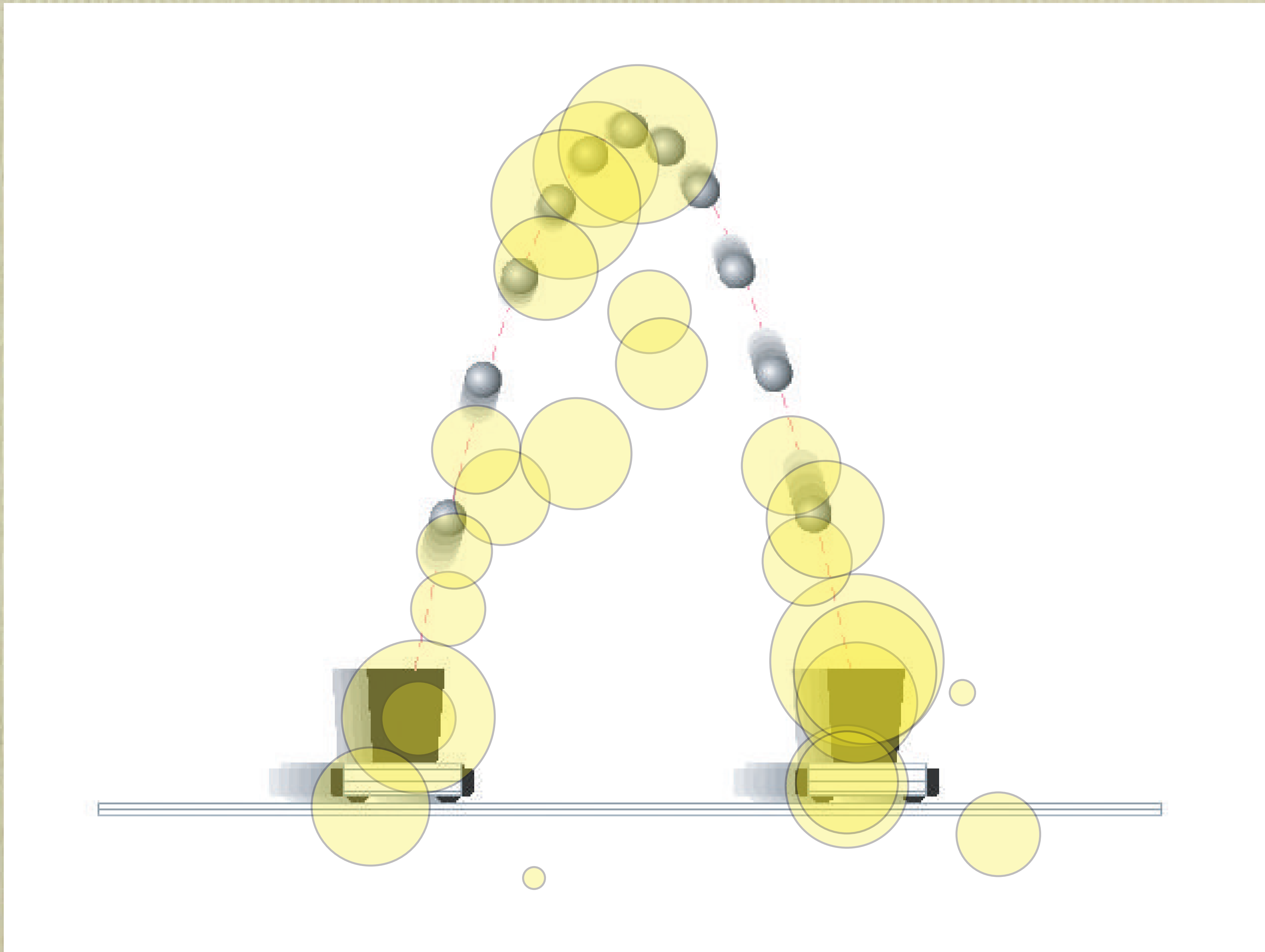
Realism



background:	realistic
physics:	unrealistic

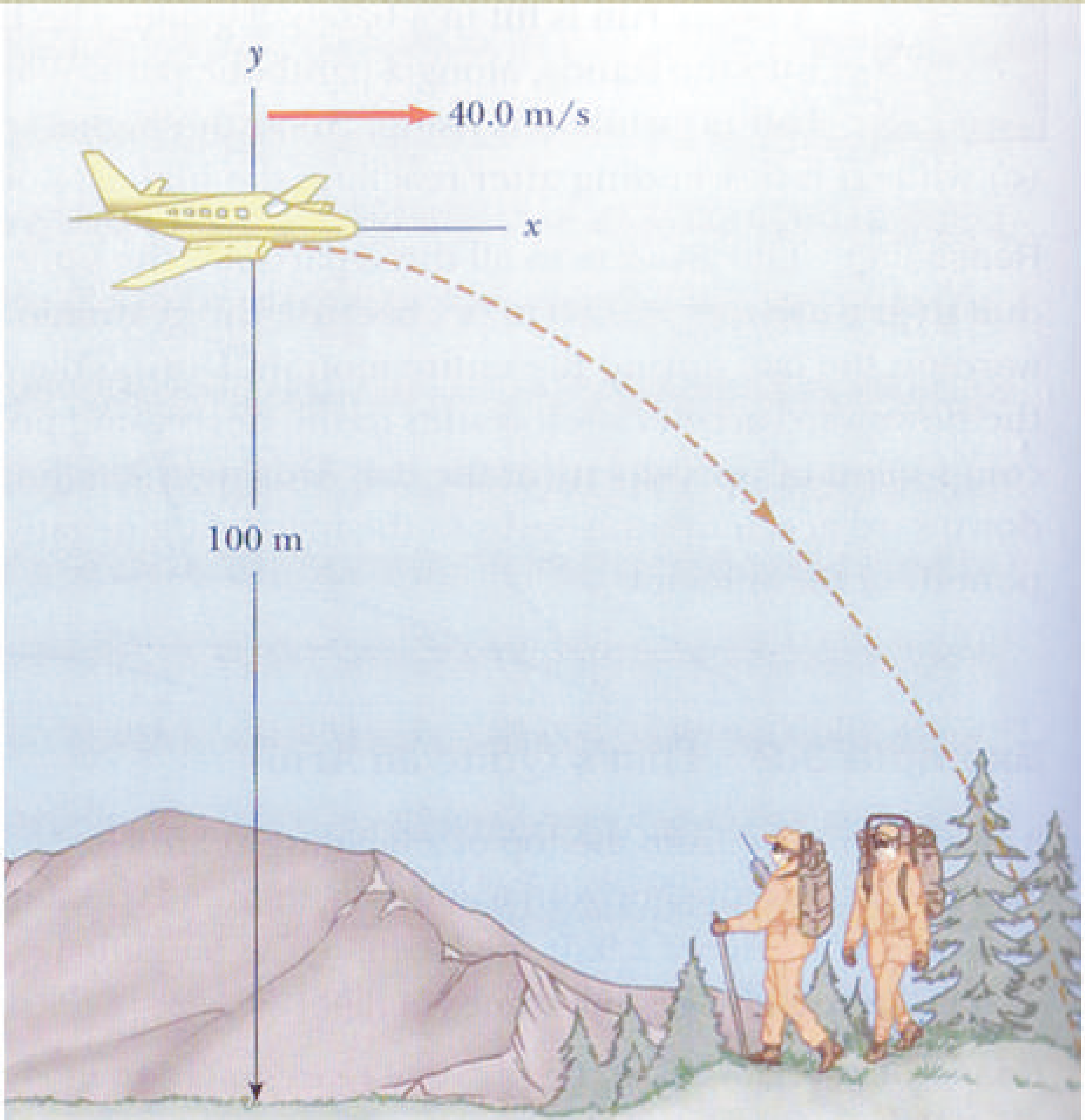
What do people look at?

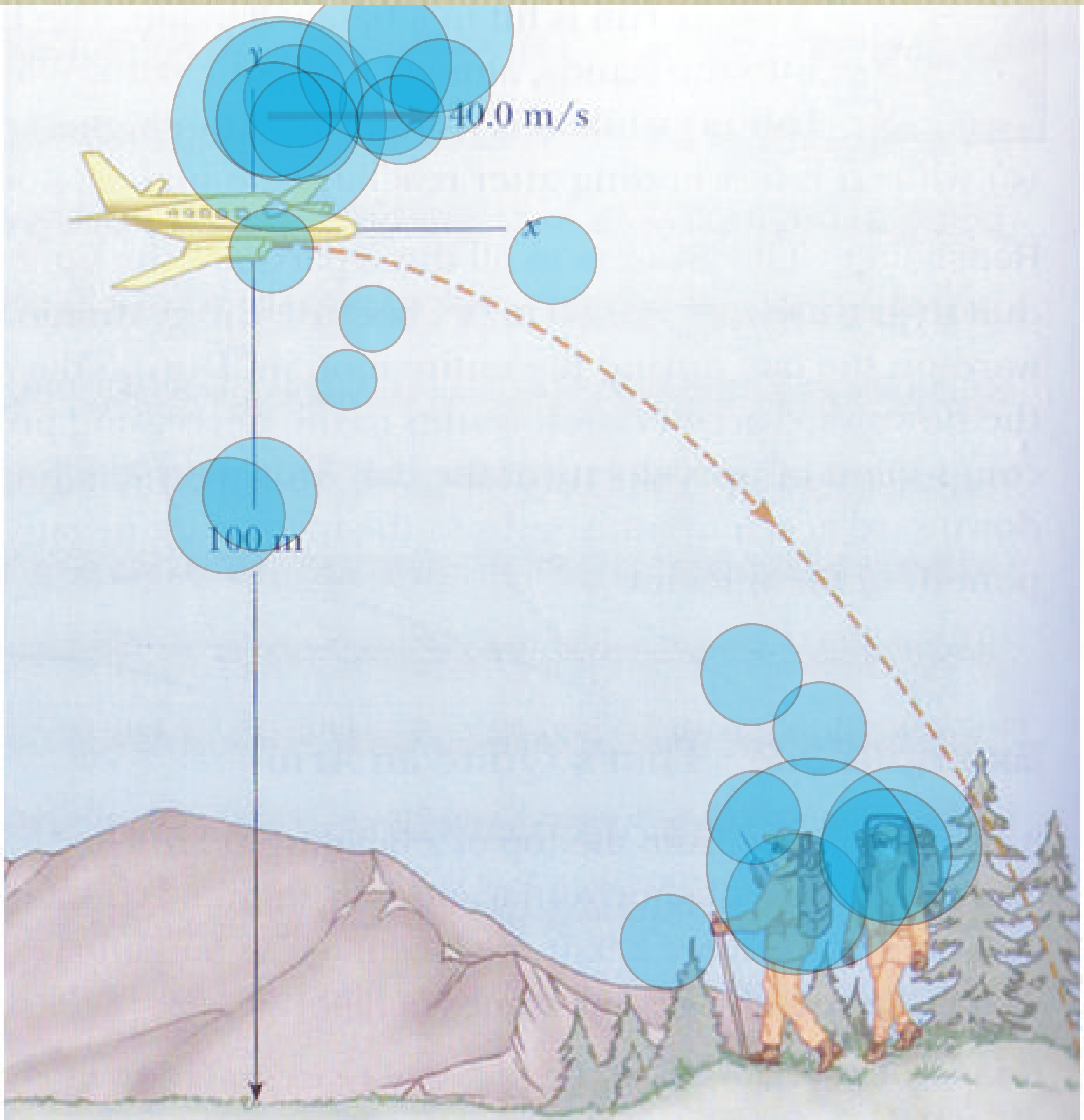




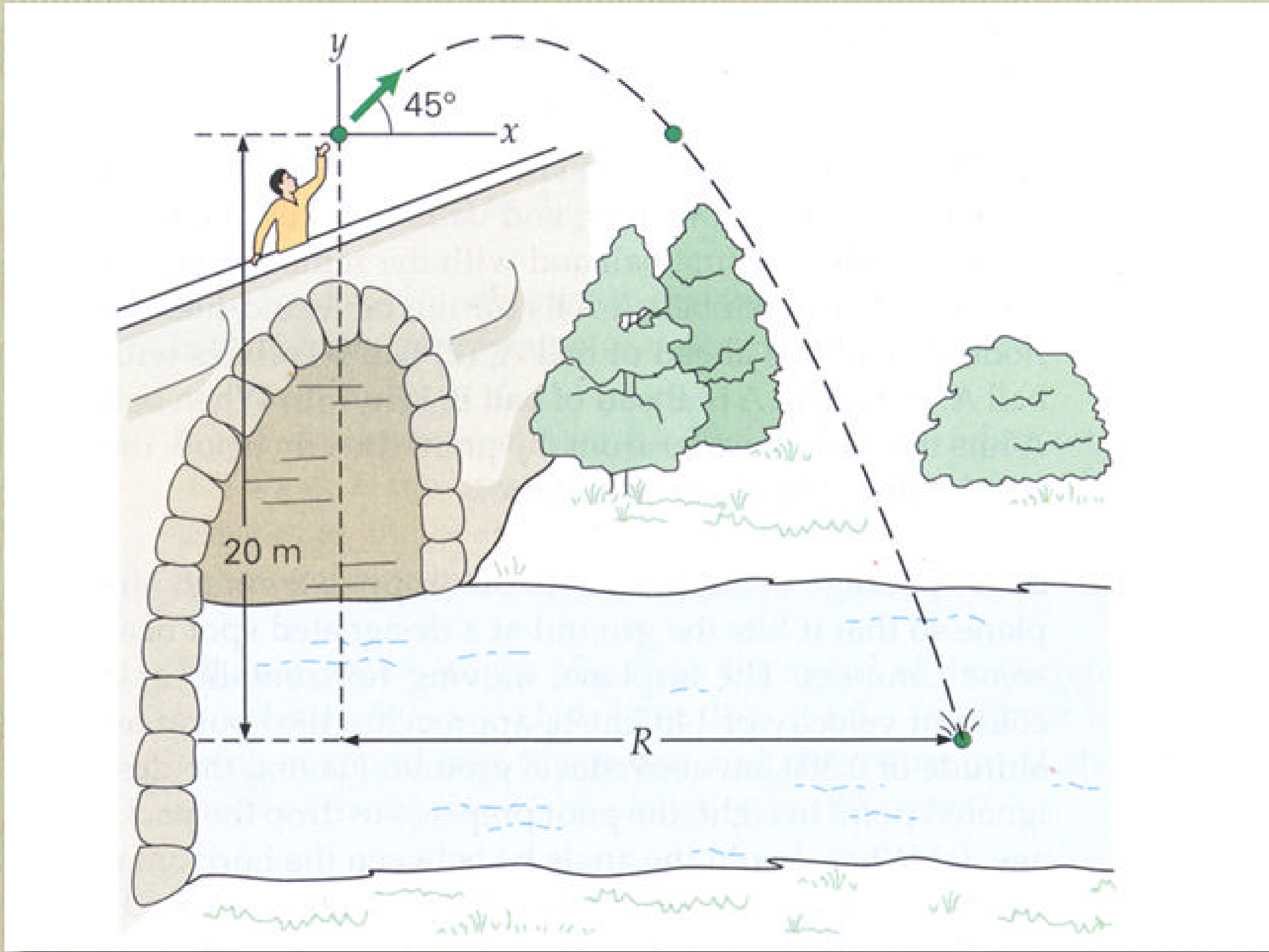
People look at

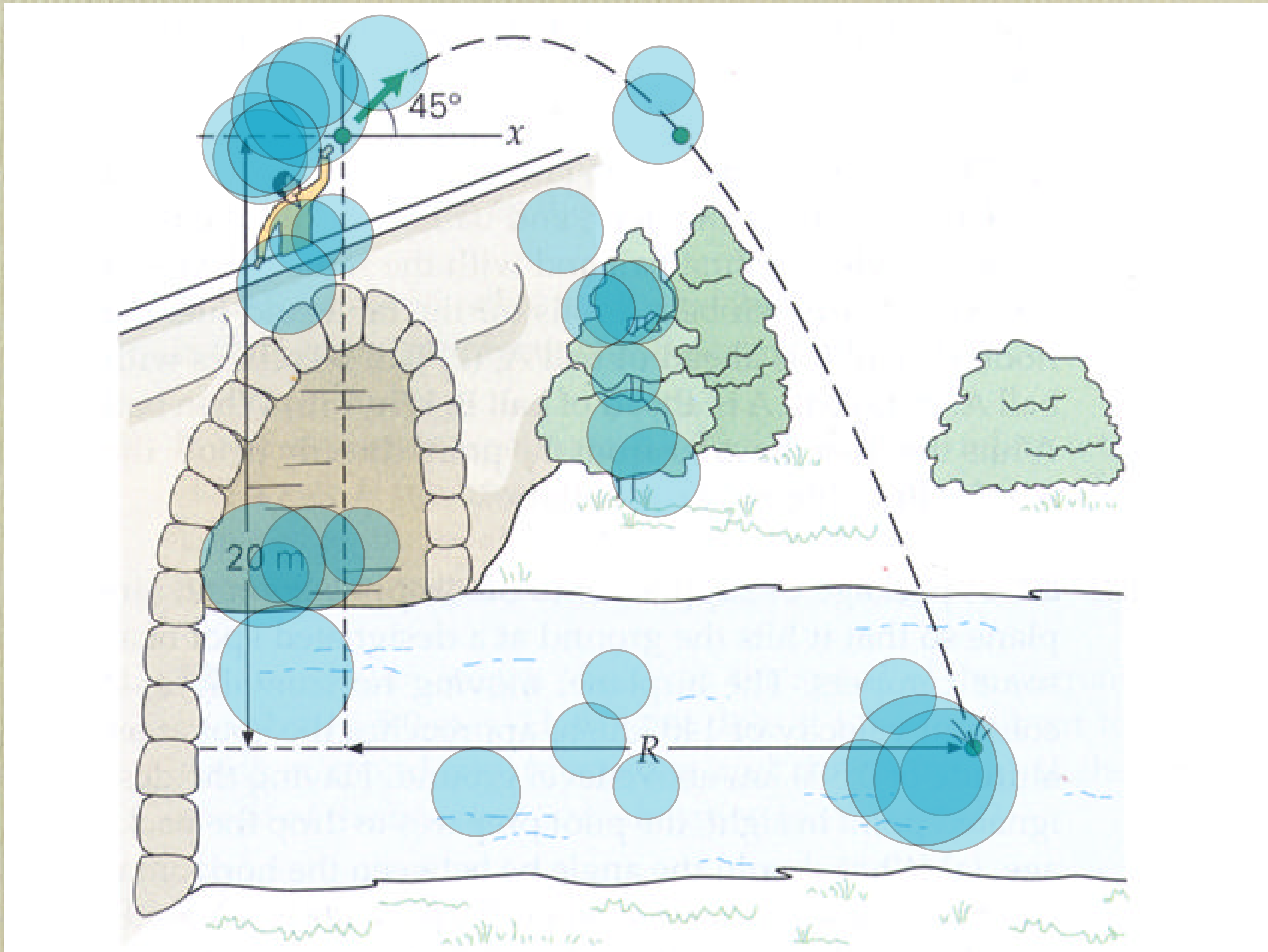
- Parabolic motion of ball
- Carts


y
40.0 m/s
x
100 m

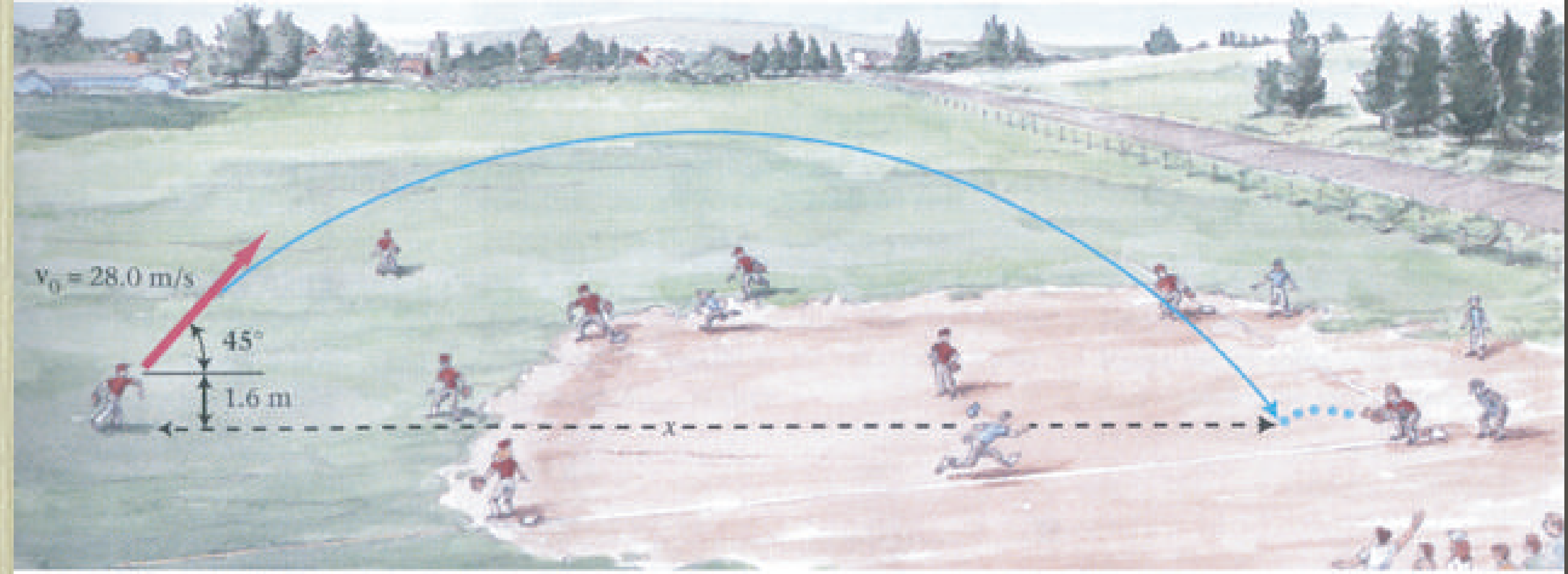


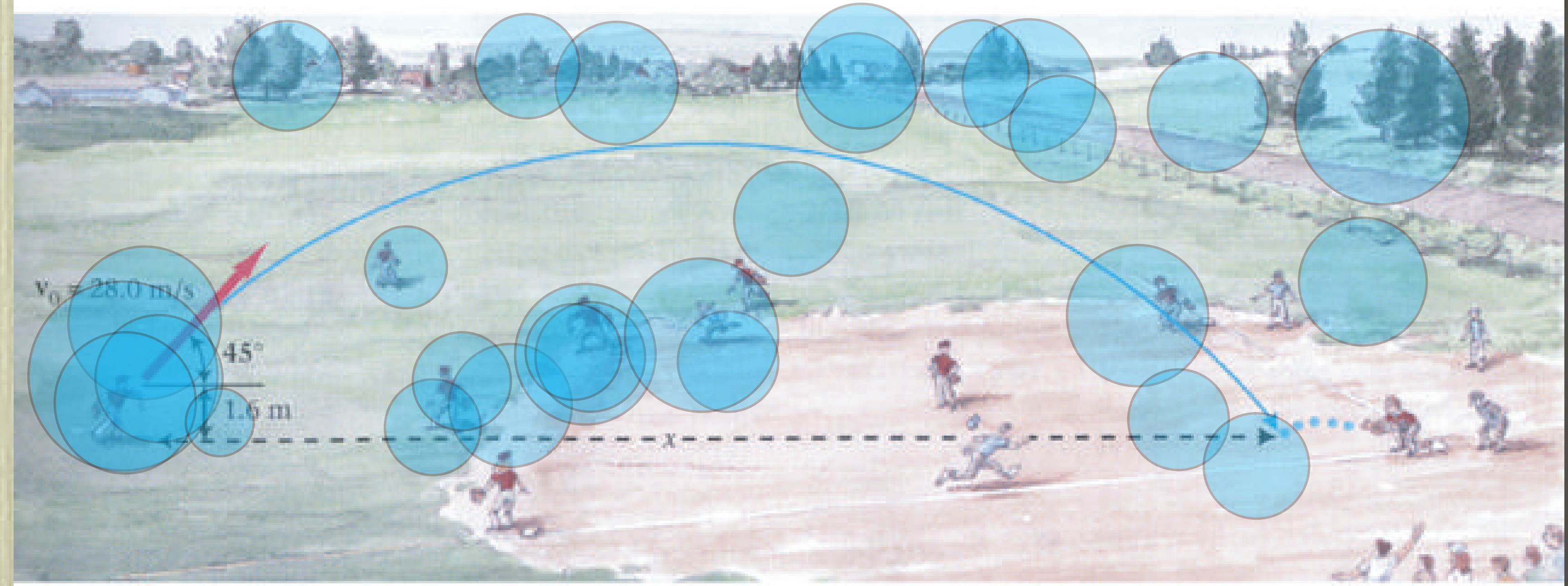
y
40.0 m/s
x
100 m


y
45°
x
20 m
R

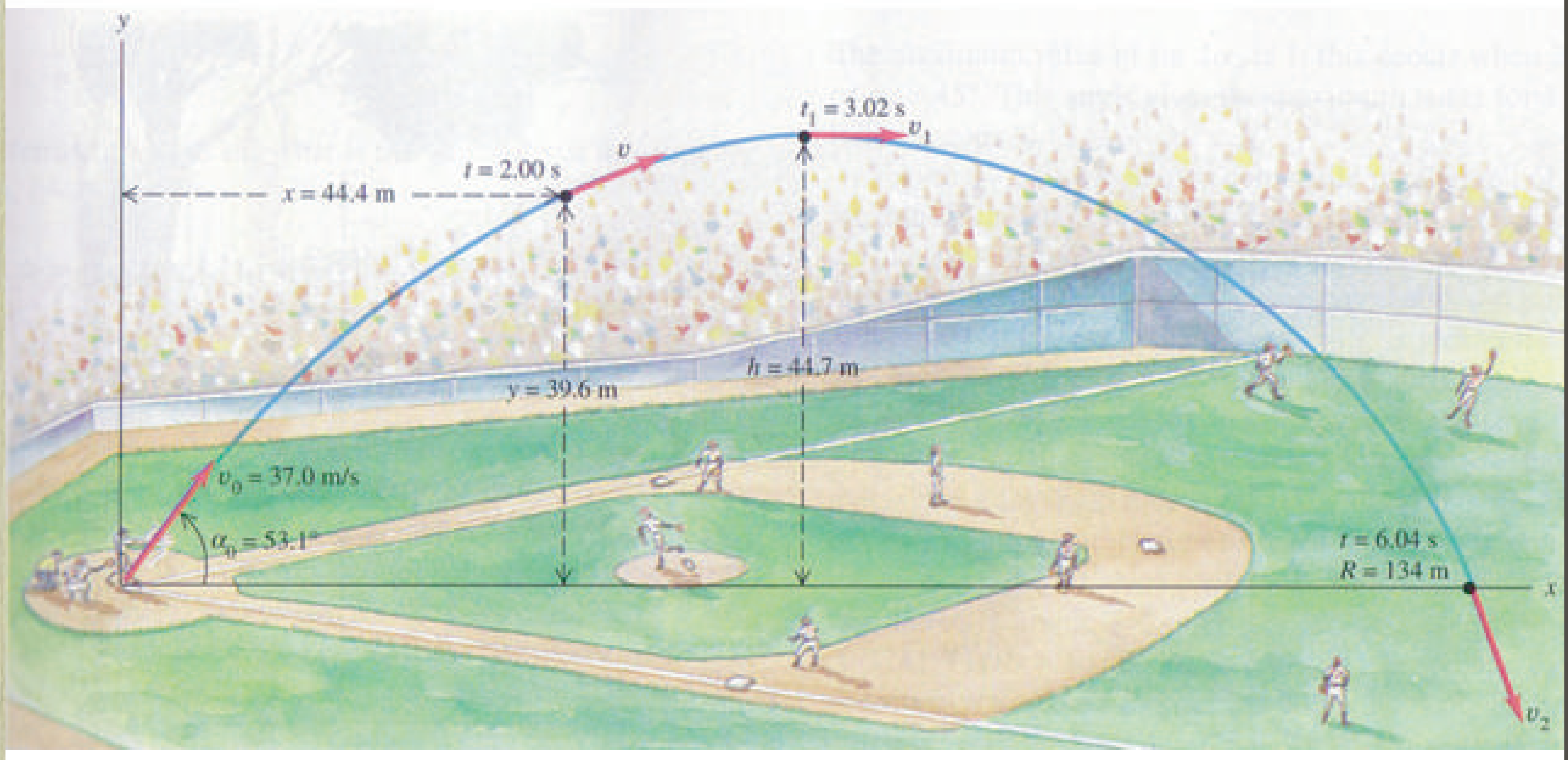


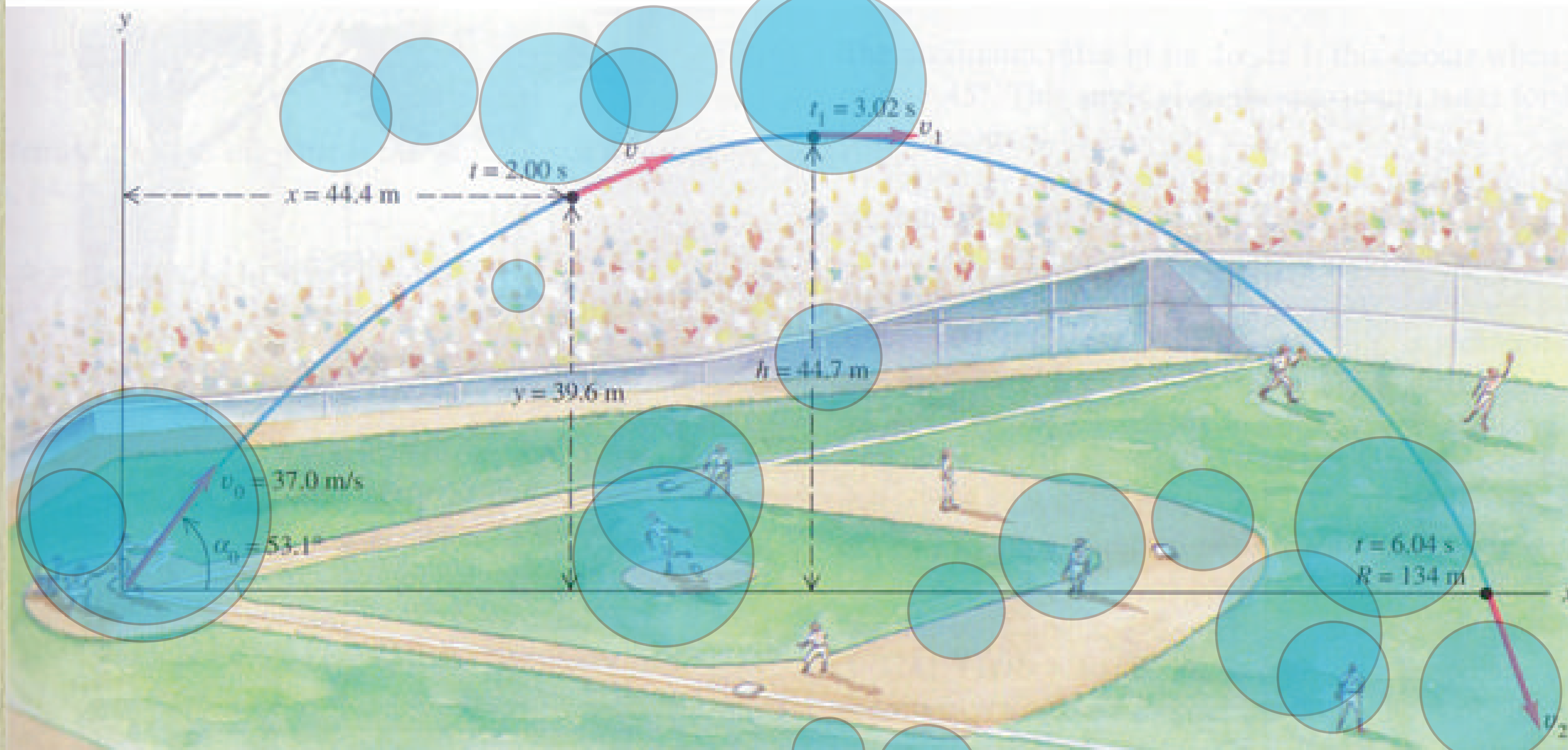
y
45°
x
20 m
R


$v_0 = 28.0$ m/s
45°
1.6 m
x



$v_0 = 28.0$ m/s
45°
1.6 m
x


y
$t_1 = 3.02$ s
v_1
$t = 2.00$ s
v
$x = 44.4$ m
$h = 44.7$ m
$y = 39.6$ m
$v_0 = 37.0$ m/s
$\alpha_0 = 53.1°$
$t = 6.04$ s
$R = 134$ m
x
v_2


y
$x = 44.4$ m
$t = 2.00$ s
v
$t_1 = 3.02$ s
v_1
$h = 44.7$ m
$y = 39.6$ m
$v_0 = 37.0$ m/s
$\alpha_0 = 53.1°$
$t = 6.04$ s
$R = 134$ m
x
v_2

People look at

- People
- Text labels
- Other (distracting) elements

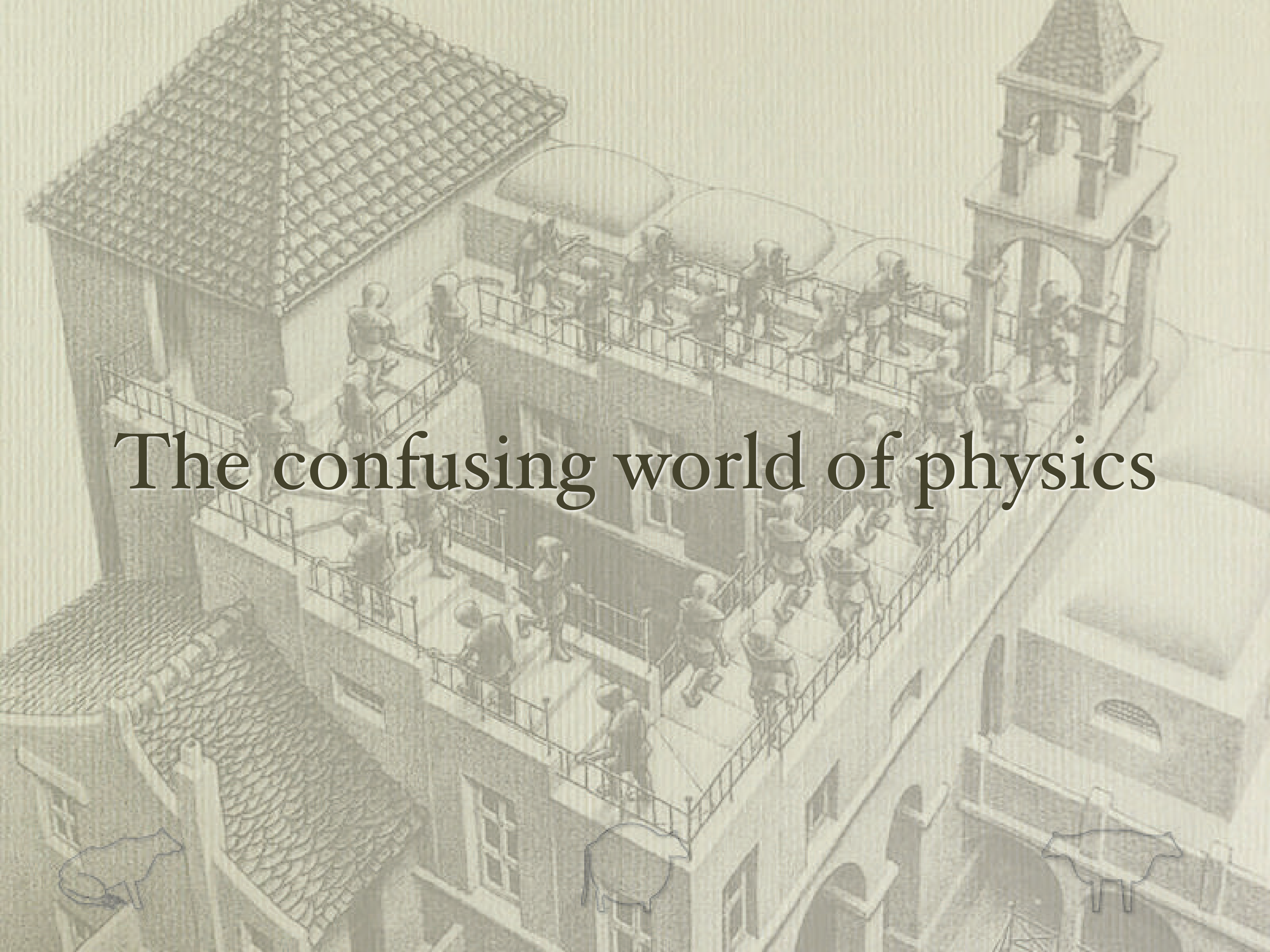
People look at

- People
- Text labels
- Other (distracting) elements

but not the parabolic motion!

Misplaced realism disconnects physics from the real world

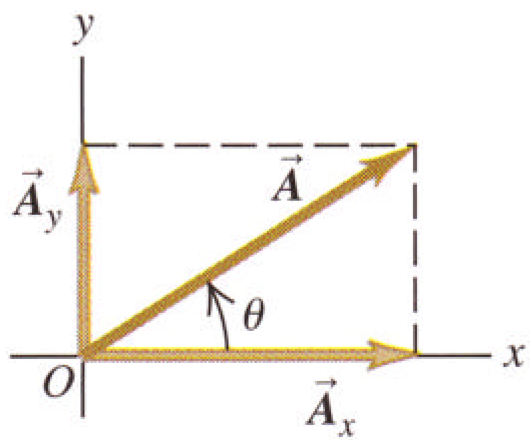
The confusing world of physics



Are vector components vectors?

Yes

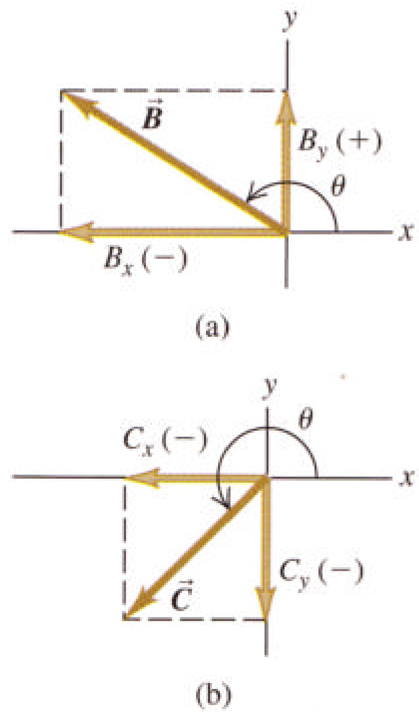
18



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.

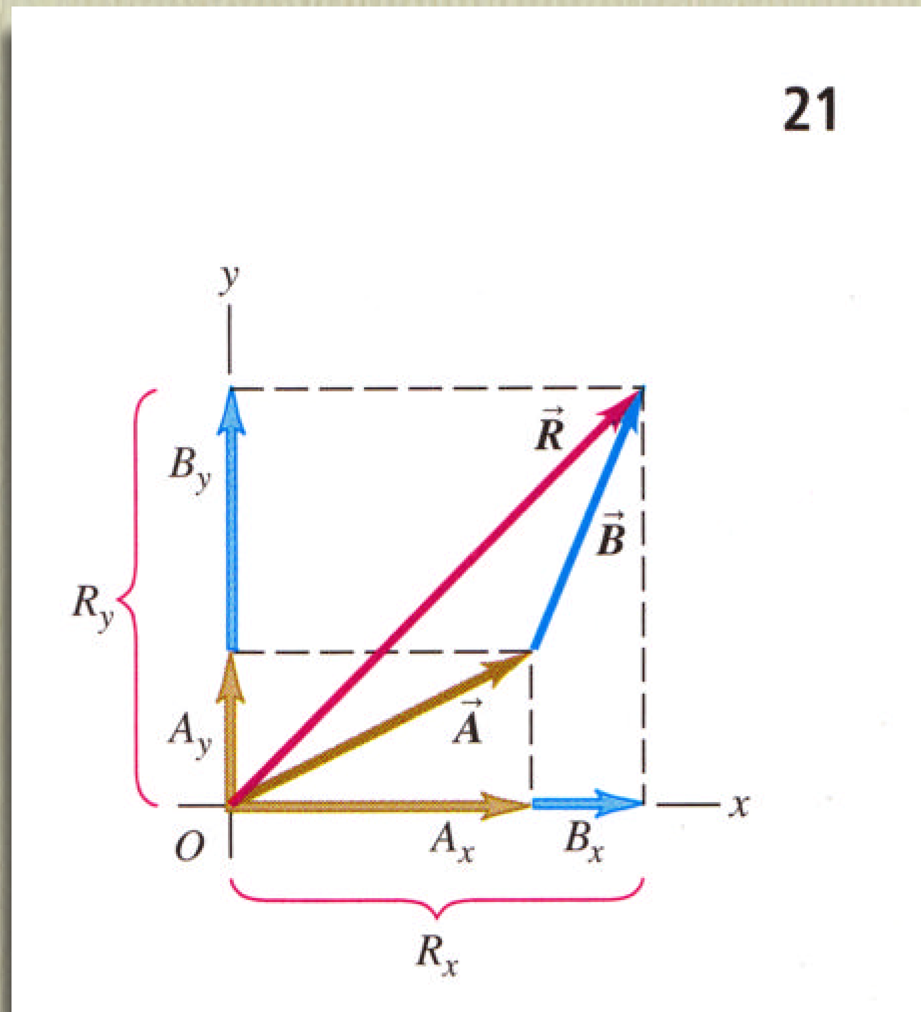
No

19



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

No

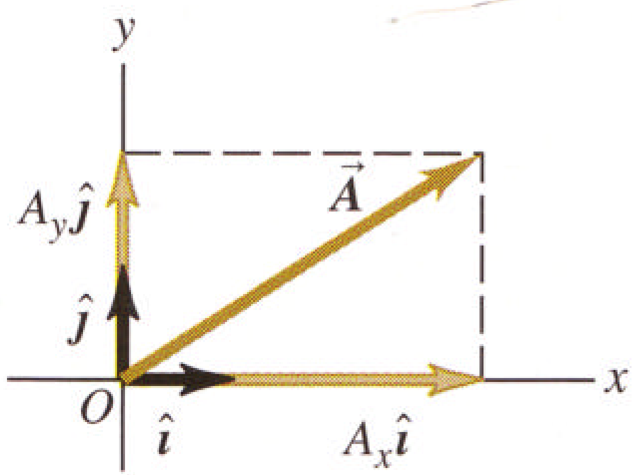


Are vector components vectors?

Yes on even pages, *no* on odd ones

Wait a minute...

23

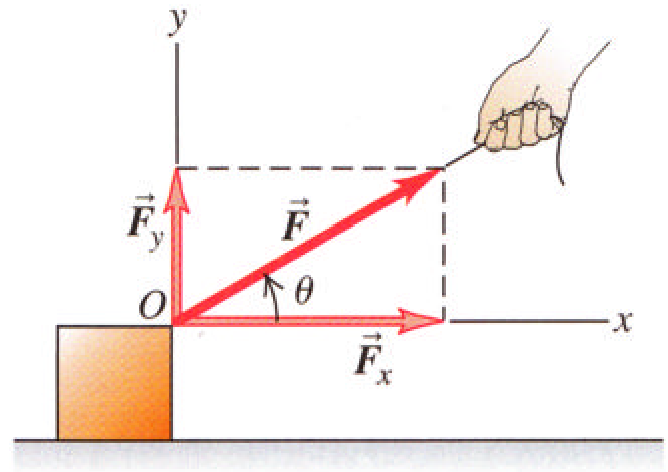


1.18 Using unit vectors, we can express a vector $\vec{A}$ in terms of its components A_x and A_y as $\vec{A} = A_x\hat{\imath} + A_y\hat{\jmath}$.

What about forces?

Yes

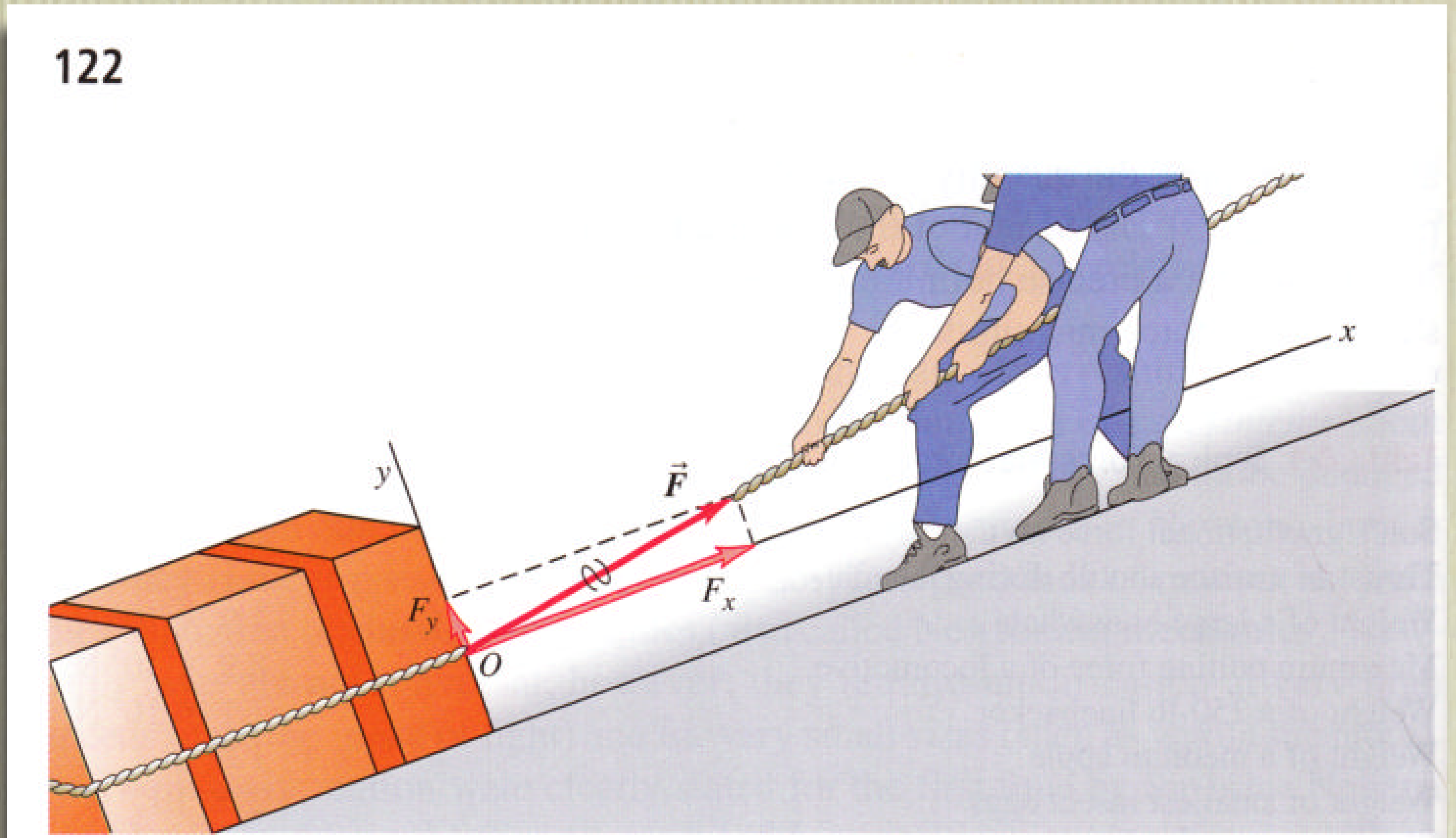
121



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 θ from the x-axis, may be replaced by its rectangular component vectors $\vec{F}_x$ and $\vec{F}_y$.

No

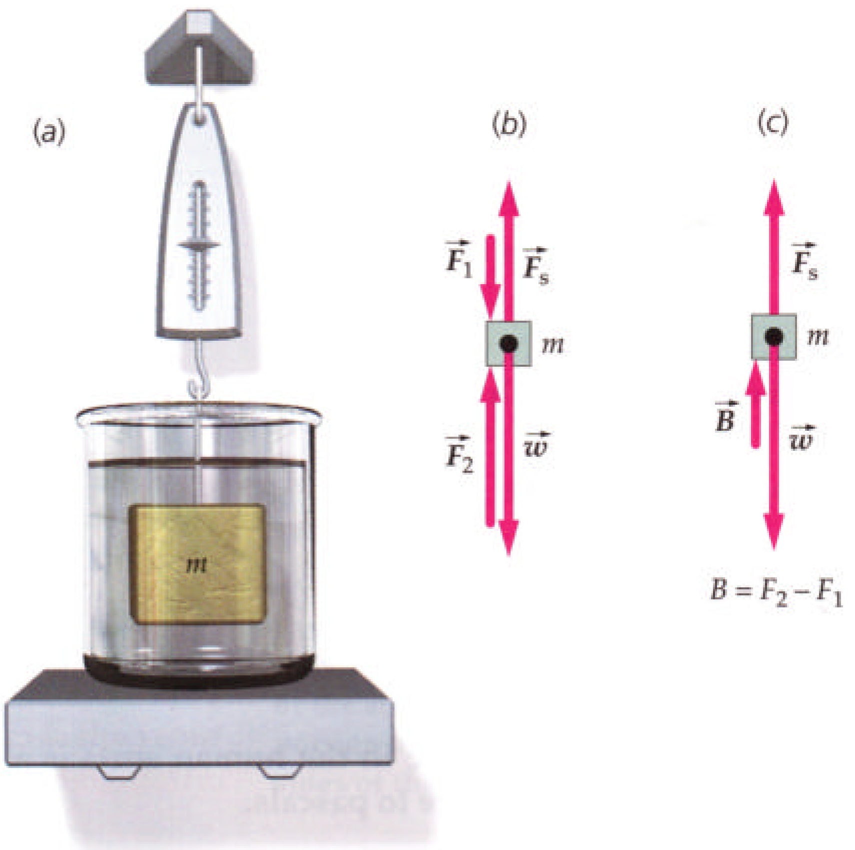


4.4 F_x and F_y are the components of $\vec{F}$ parallel and perpendicular to the sloping surface of the inclined plane.

“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 13-9*b* 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 13-9*c*). The buoyant force occurs because the pressure of the fluid at the bottom of the object is greater than that at the top.



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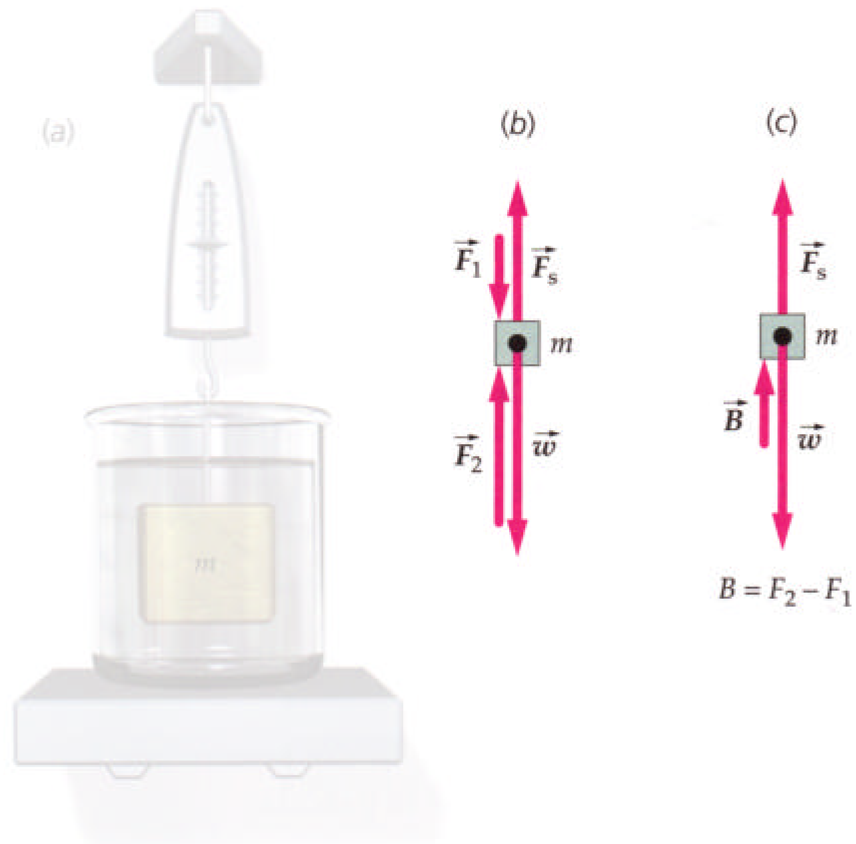

Working with vectors

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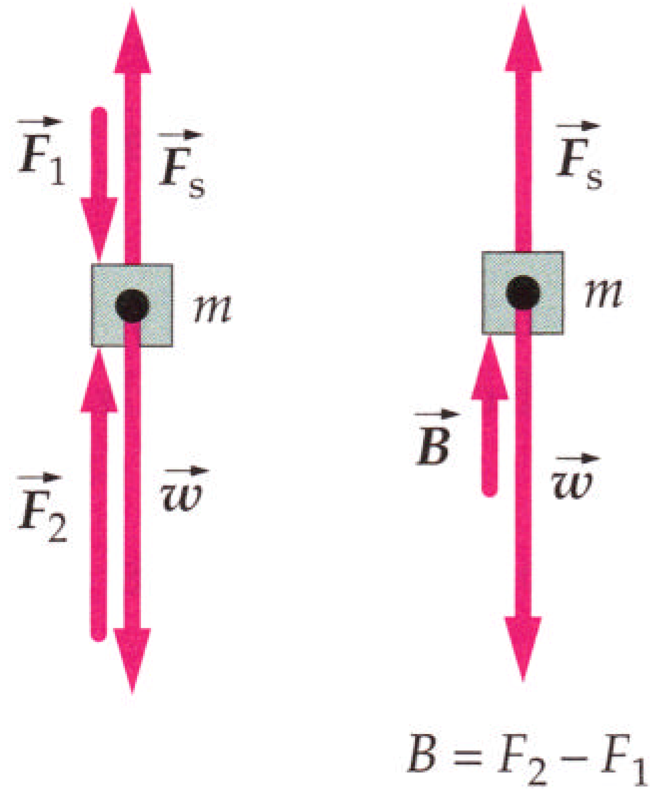
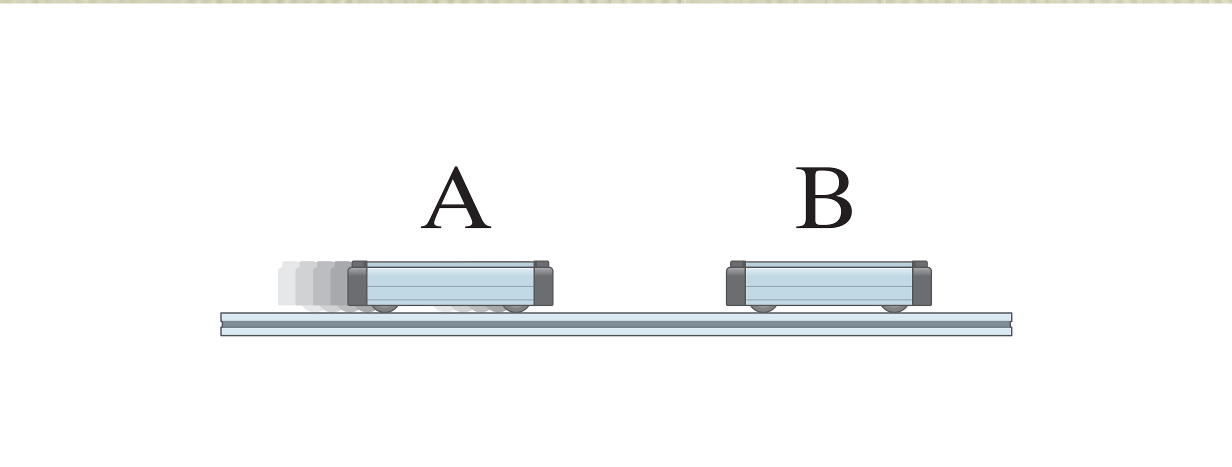
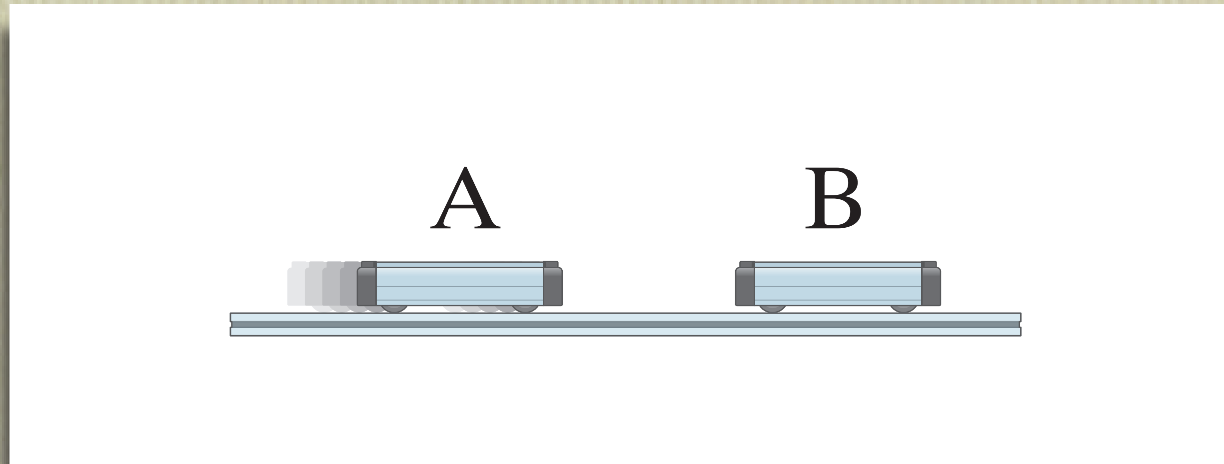


Because we know what is meant,
we are unconscious of errors

Conservation

Consider collision on low-friction track





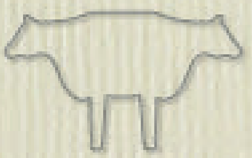
“ The momentum of cart B is not conserved”

“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

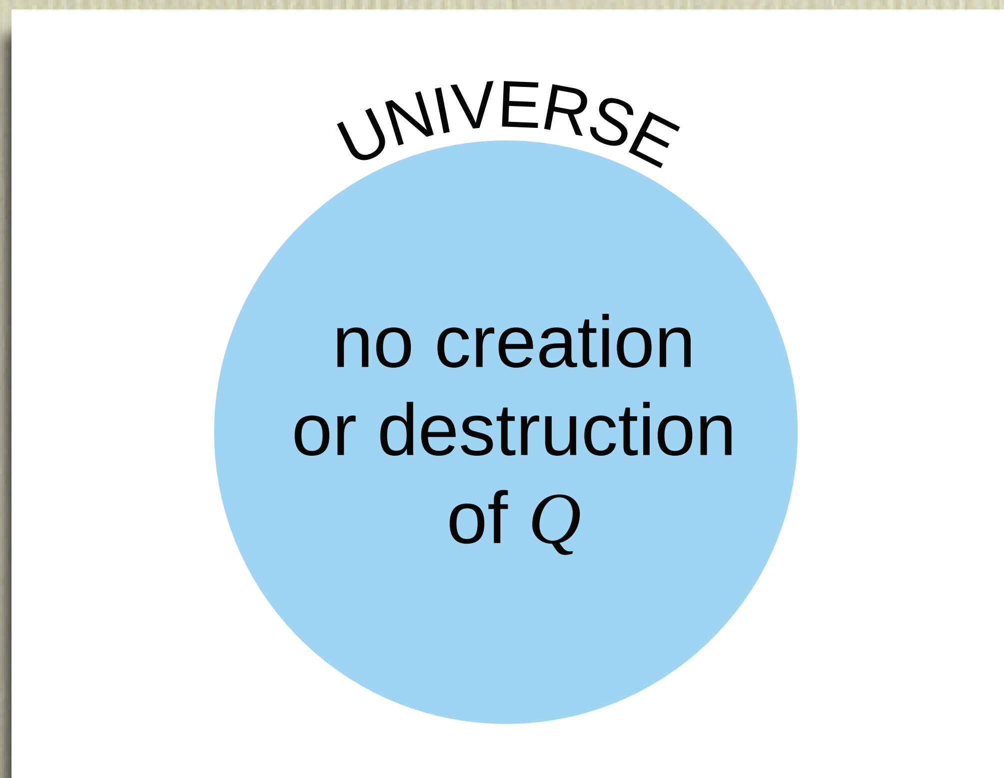
- System (universe, environment)
- Extensive quantities
- Destruction/creation
- Interactions (transfer, flow, boundary)
- Constant (no change over time)

Conservation

How to express "conservation" of quantity Q?

Conservation

How to express “conservation” of quantity Q?



Conservation

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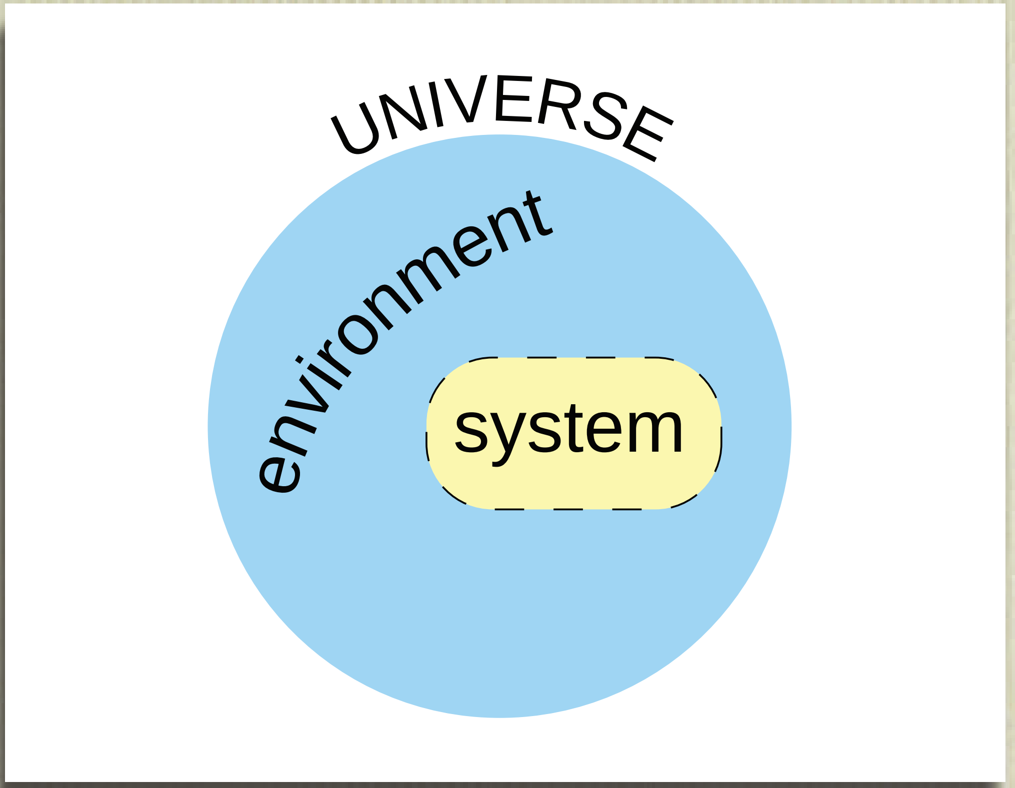
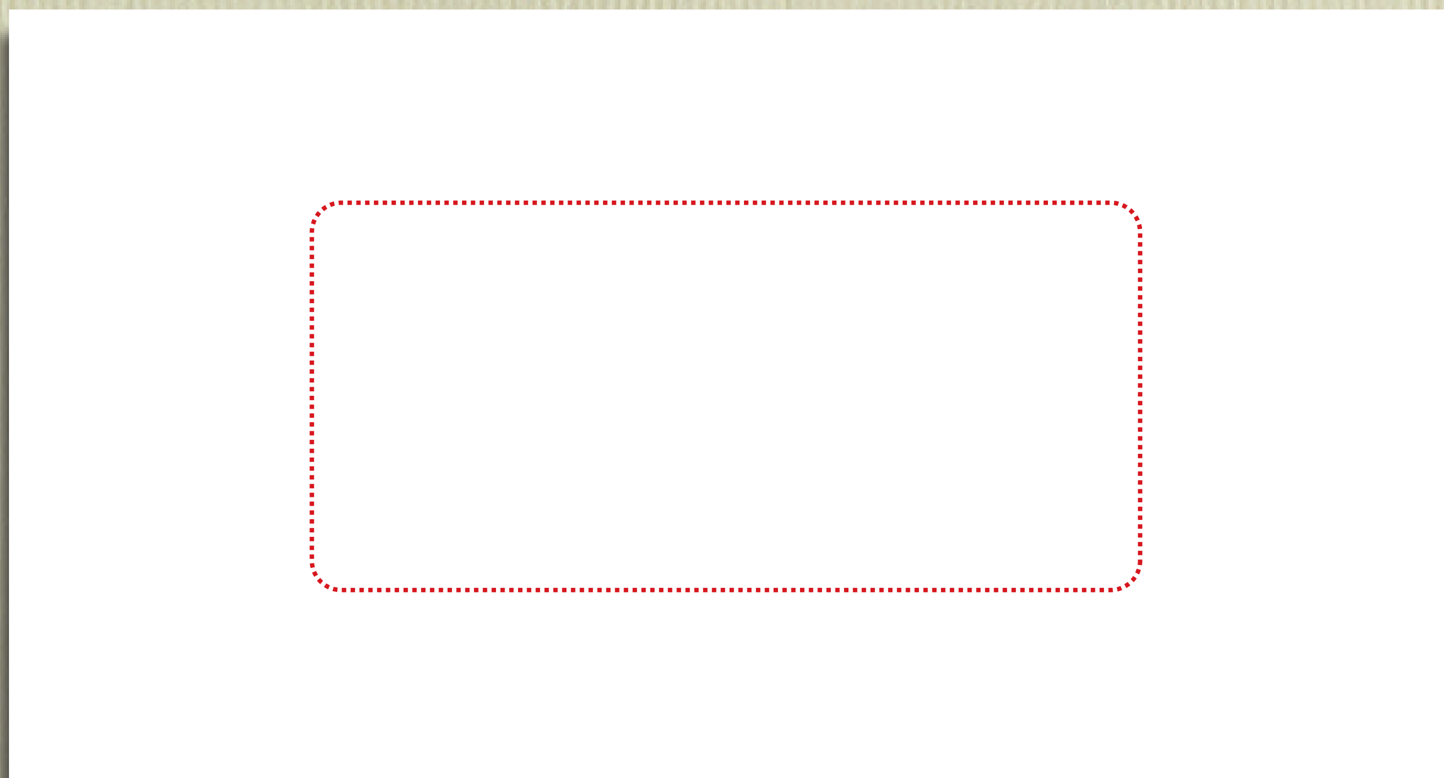


Conservation

How can Q change?



Conservation

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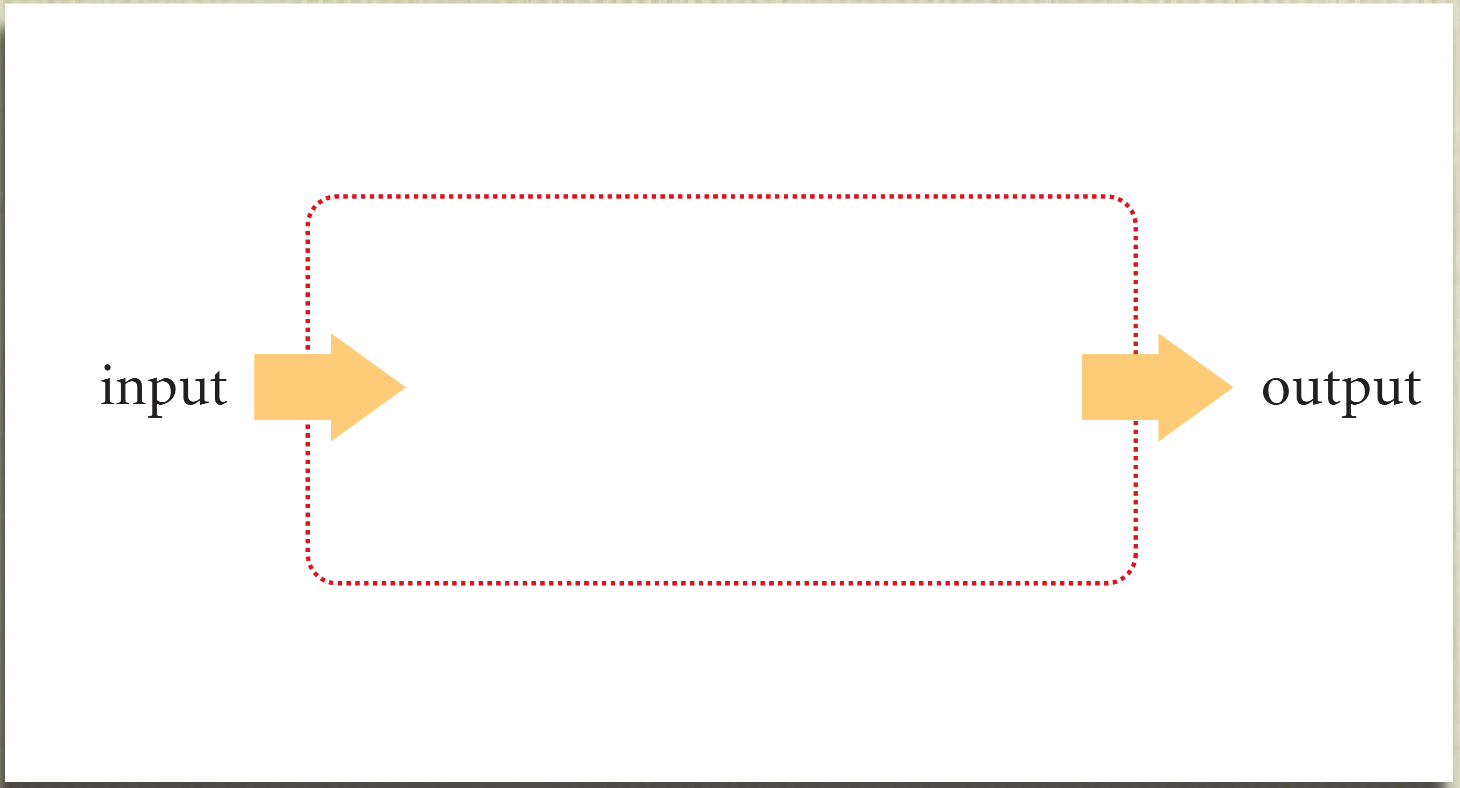

Conservation

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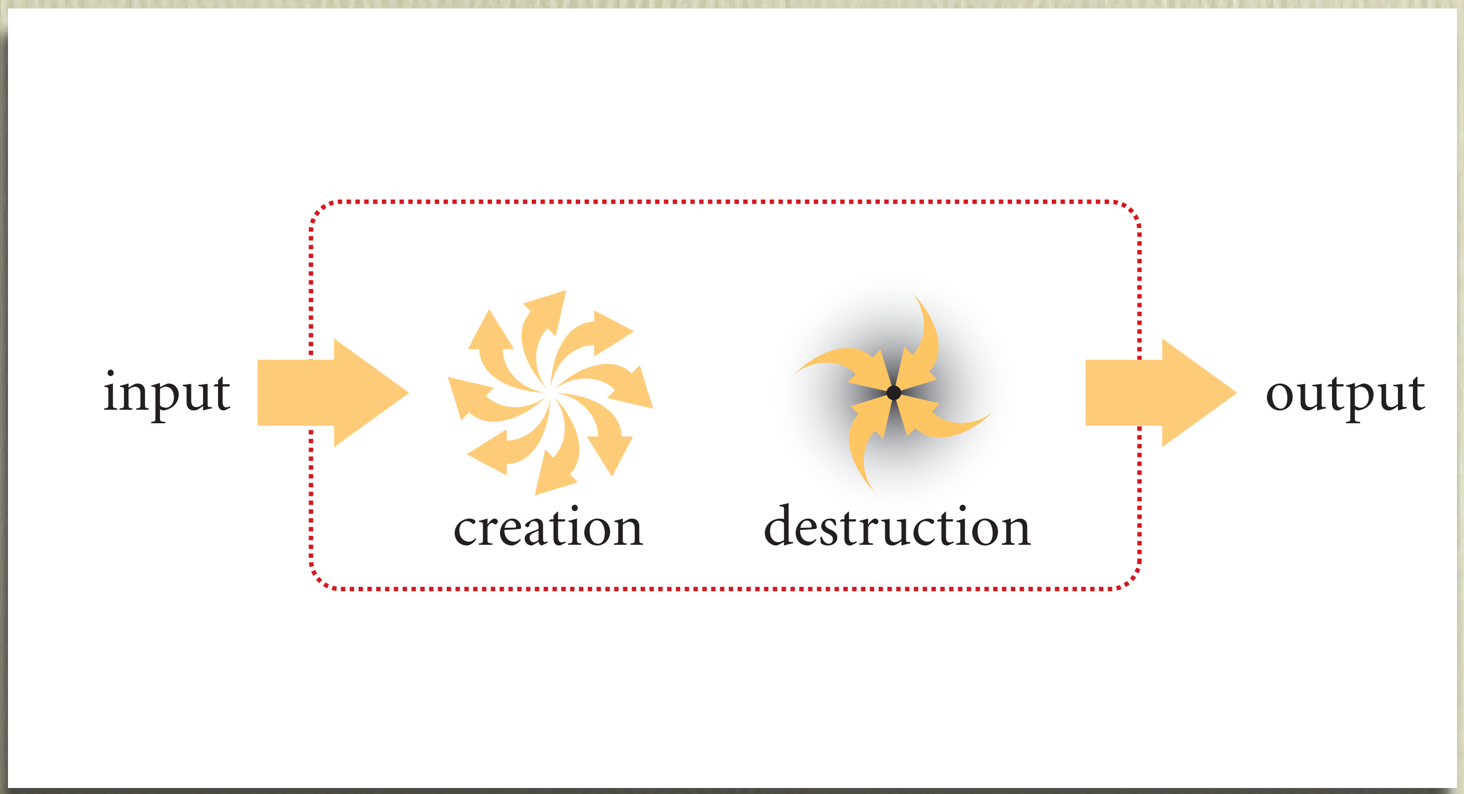
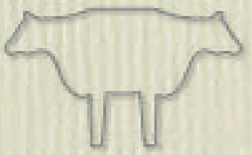
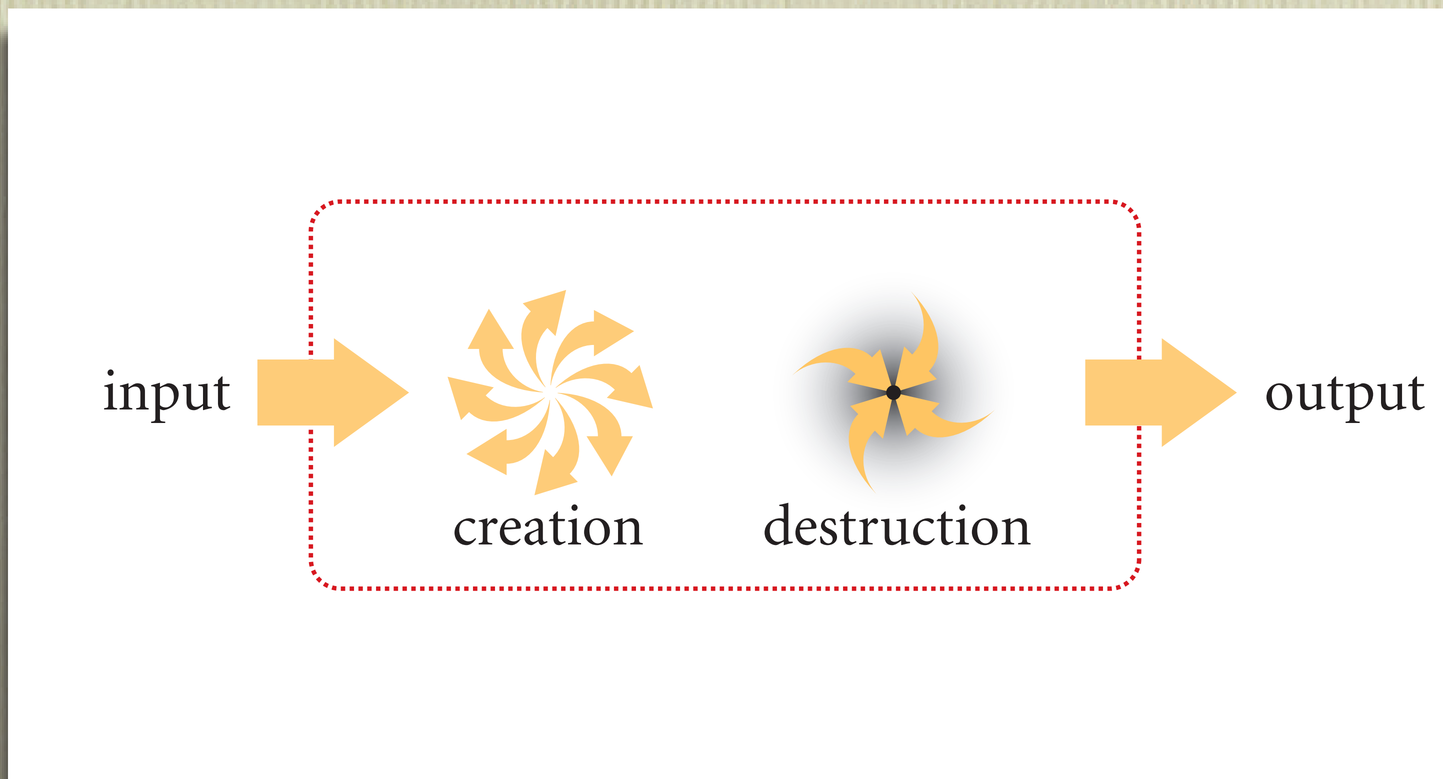






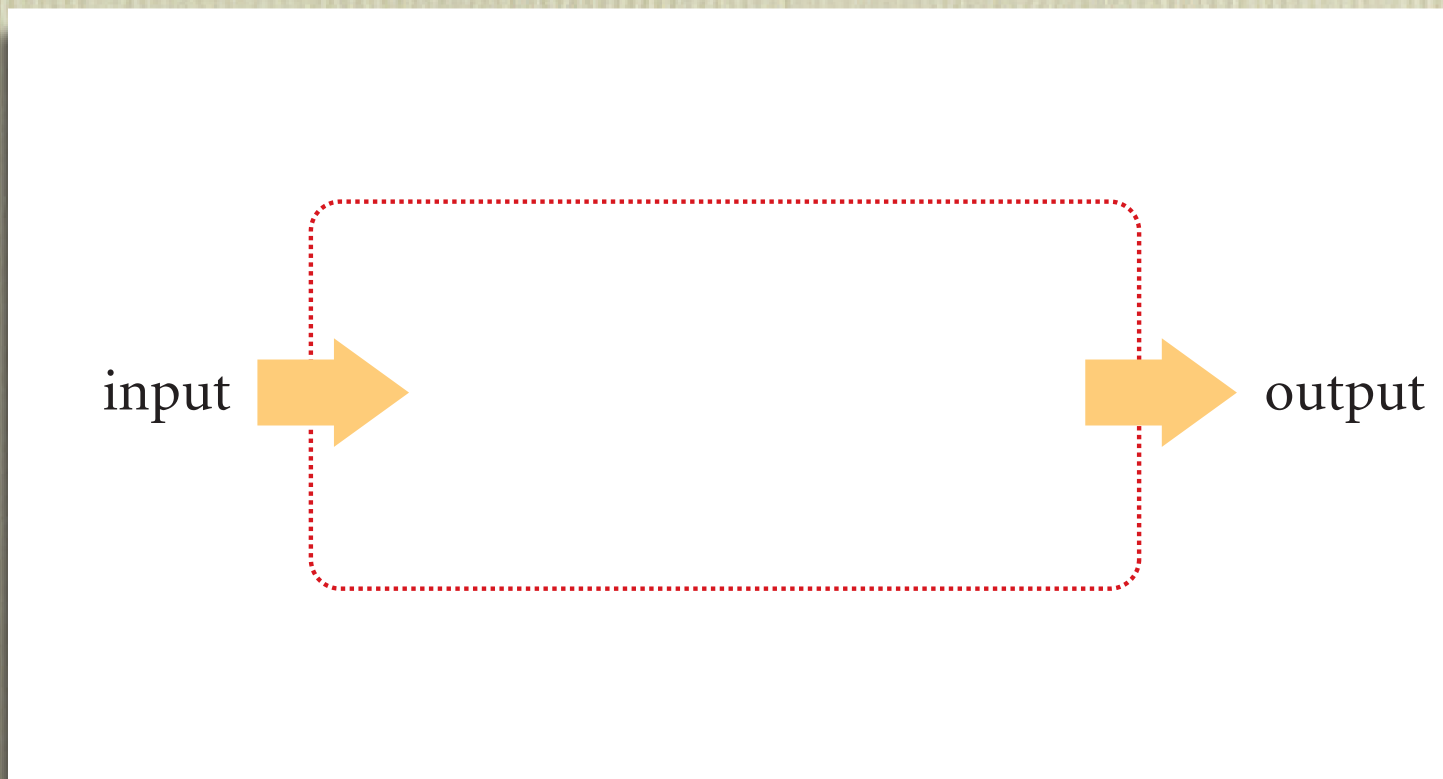
Conservation

$$\Delta Q = J_Q + S_Q$$



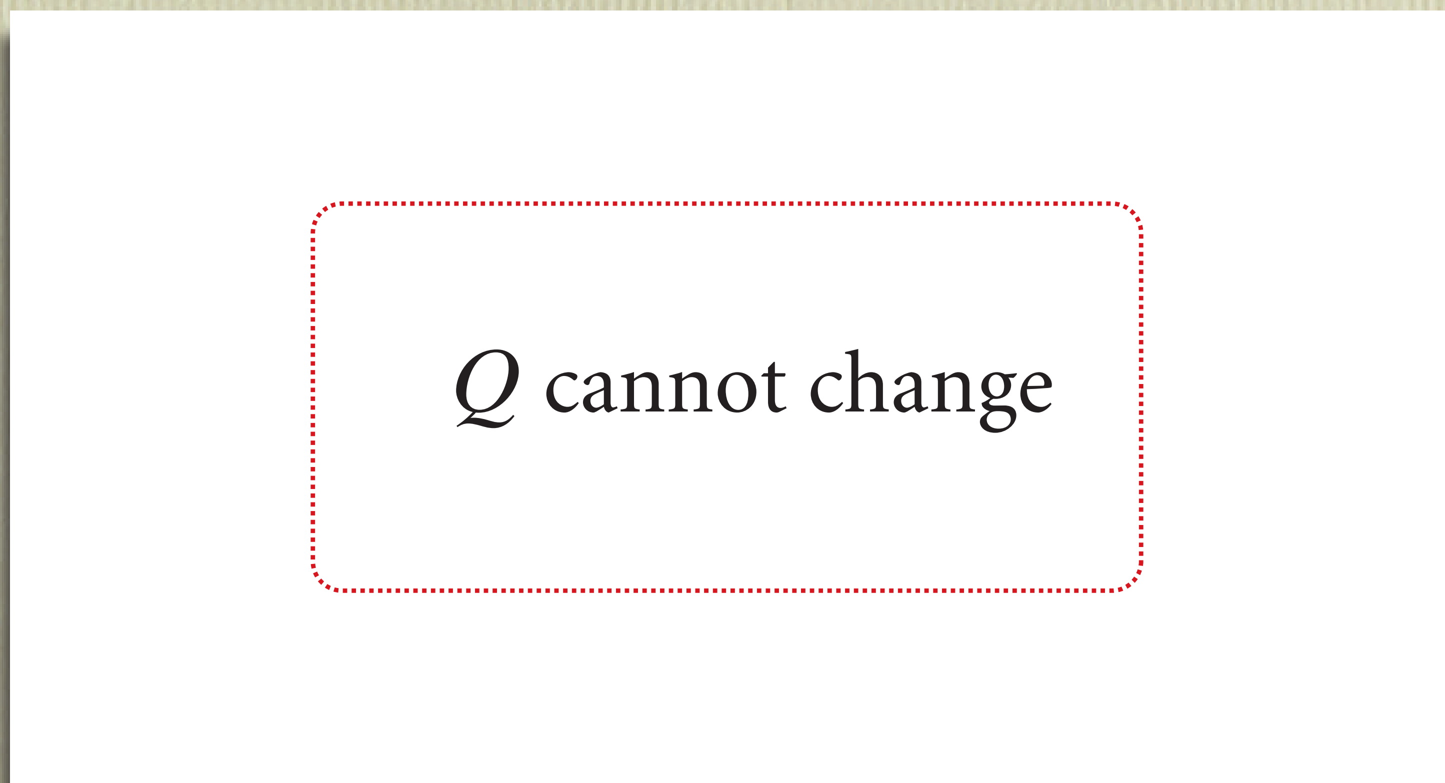
Conservation

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



Conservation

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



Conservation

conservation + isolation = no change

Q cannot change

Conservation

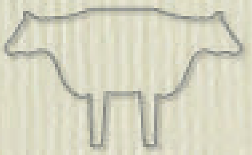
What I told my students:

Conservation

What I told my students:

1. Conservation laws most basic principles





Conservation

What I told my students:

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

Conservation

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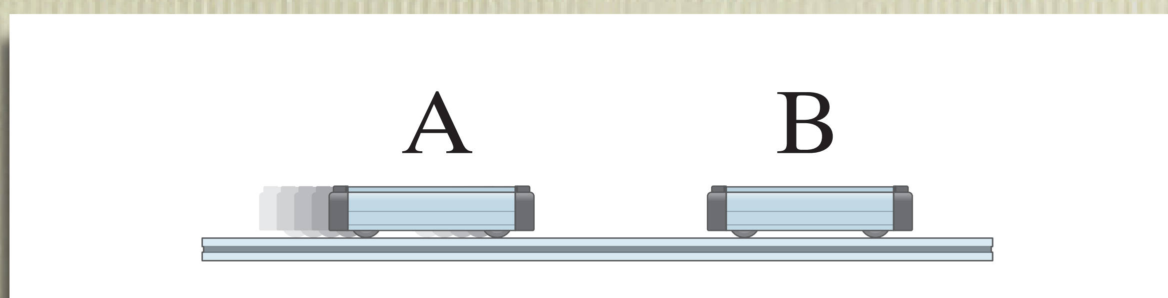

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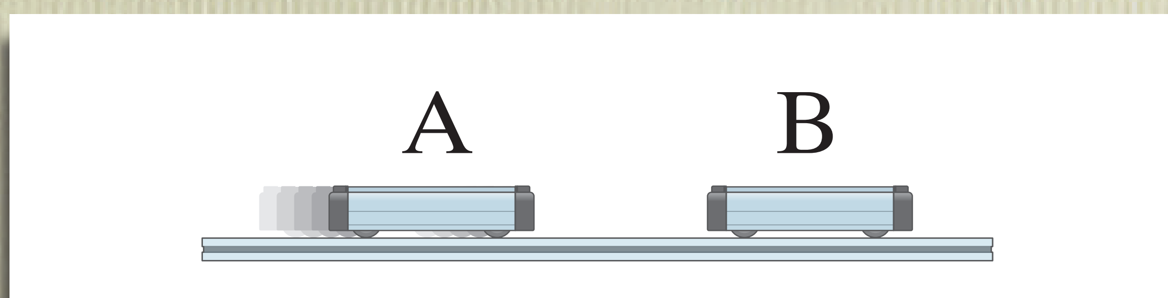


3. Momentum of cart *B* is not conserved

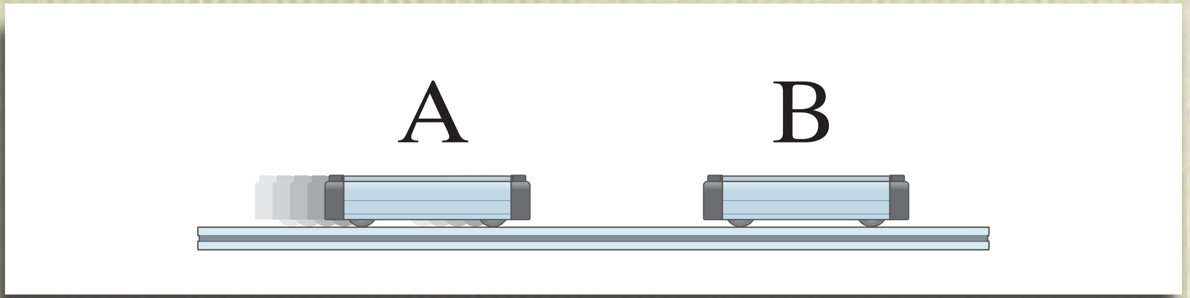
Dear Professor,

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

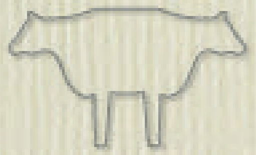
A conserved quantity:

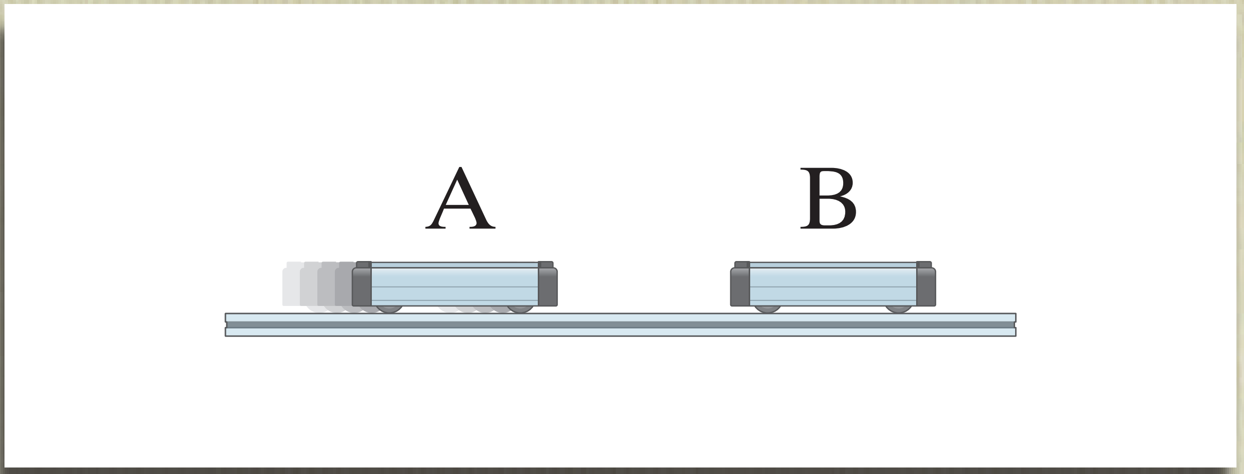
1. is *always* conserved

2. is *constant* (not *conserved*) for isolated systems

3. can *only* change due to transfer across boundary







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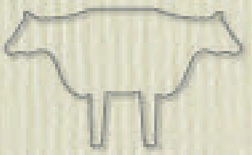

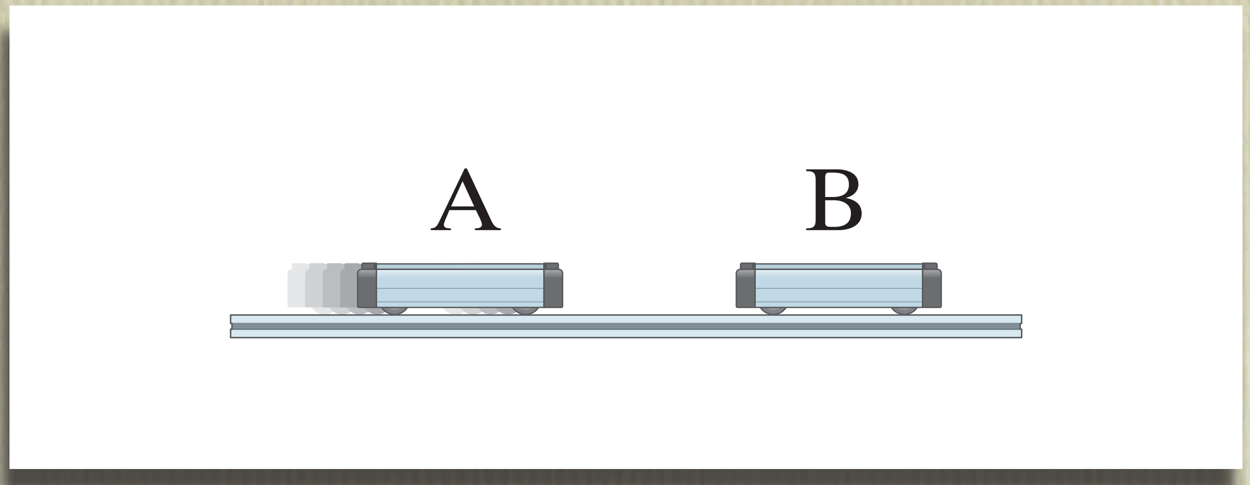

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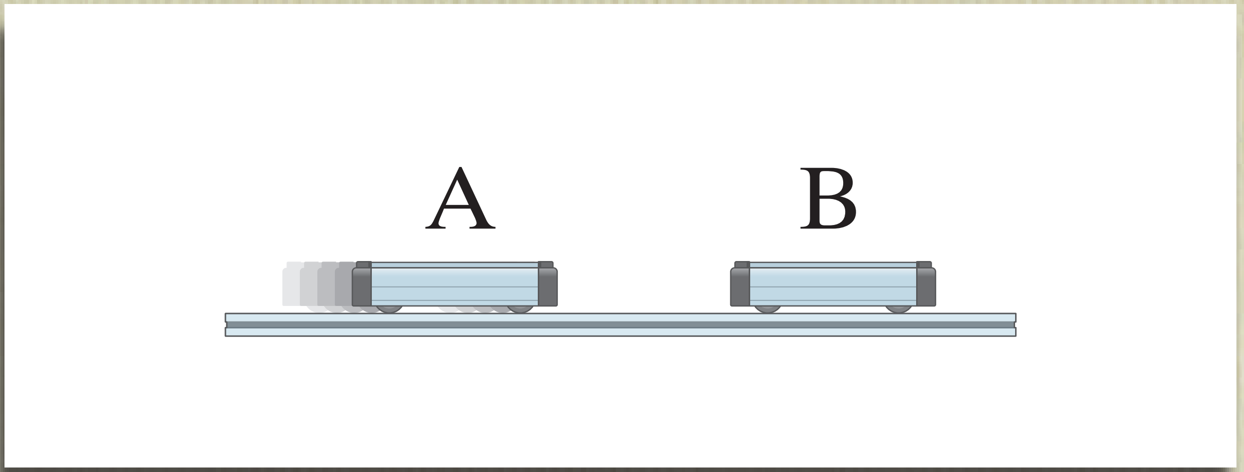

" The momentum of cart B is not constant"

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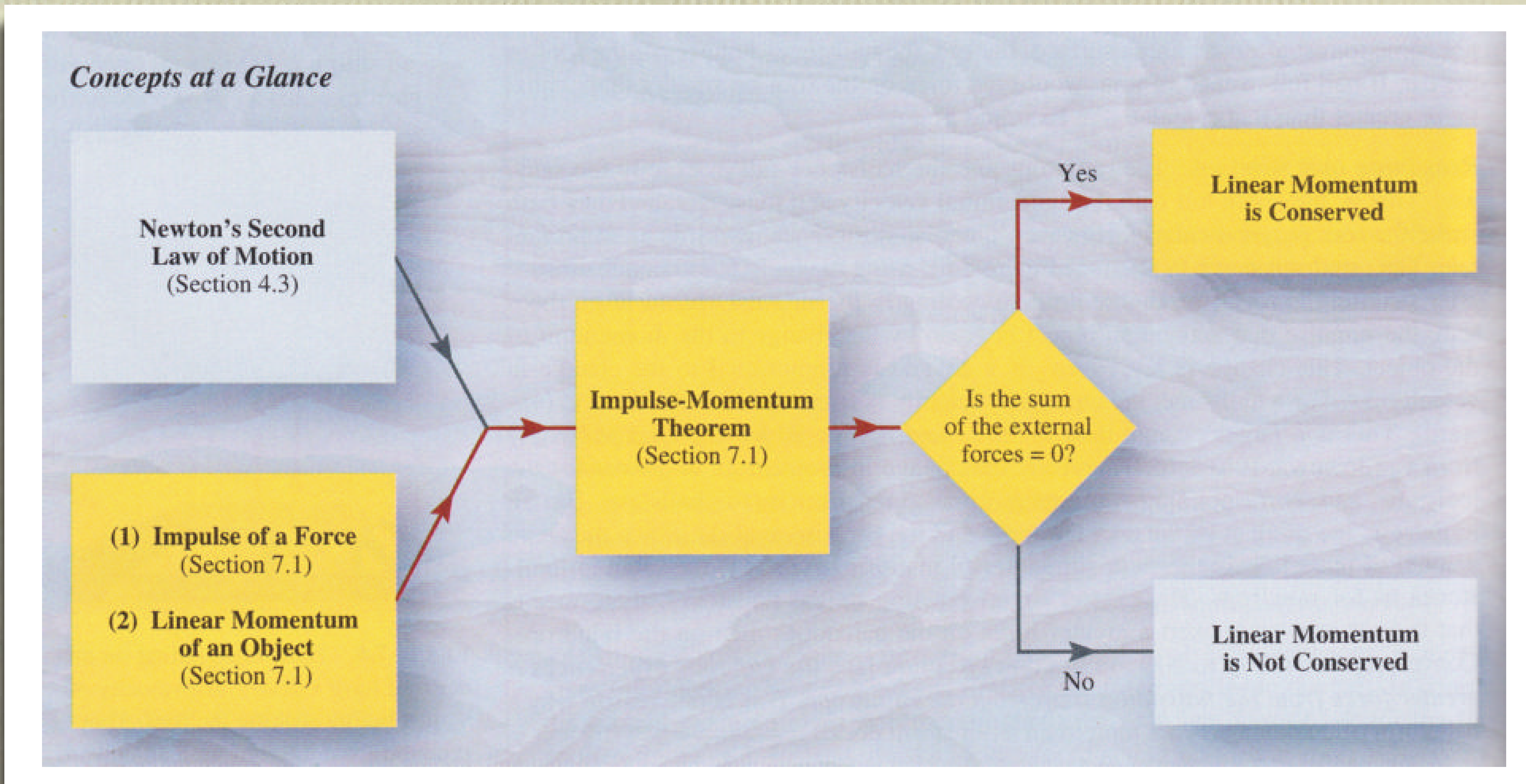
It's not just me!



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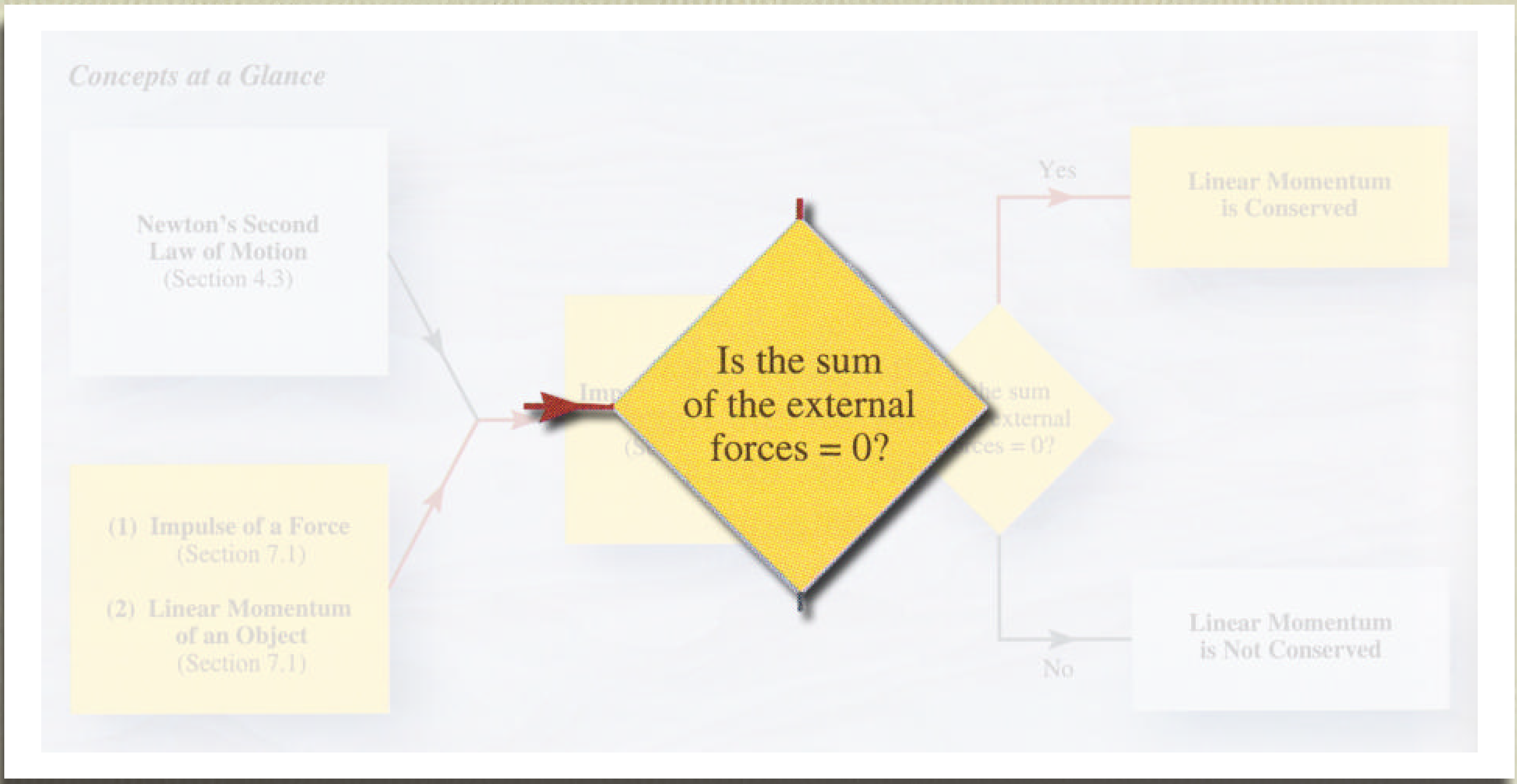

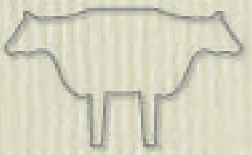

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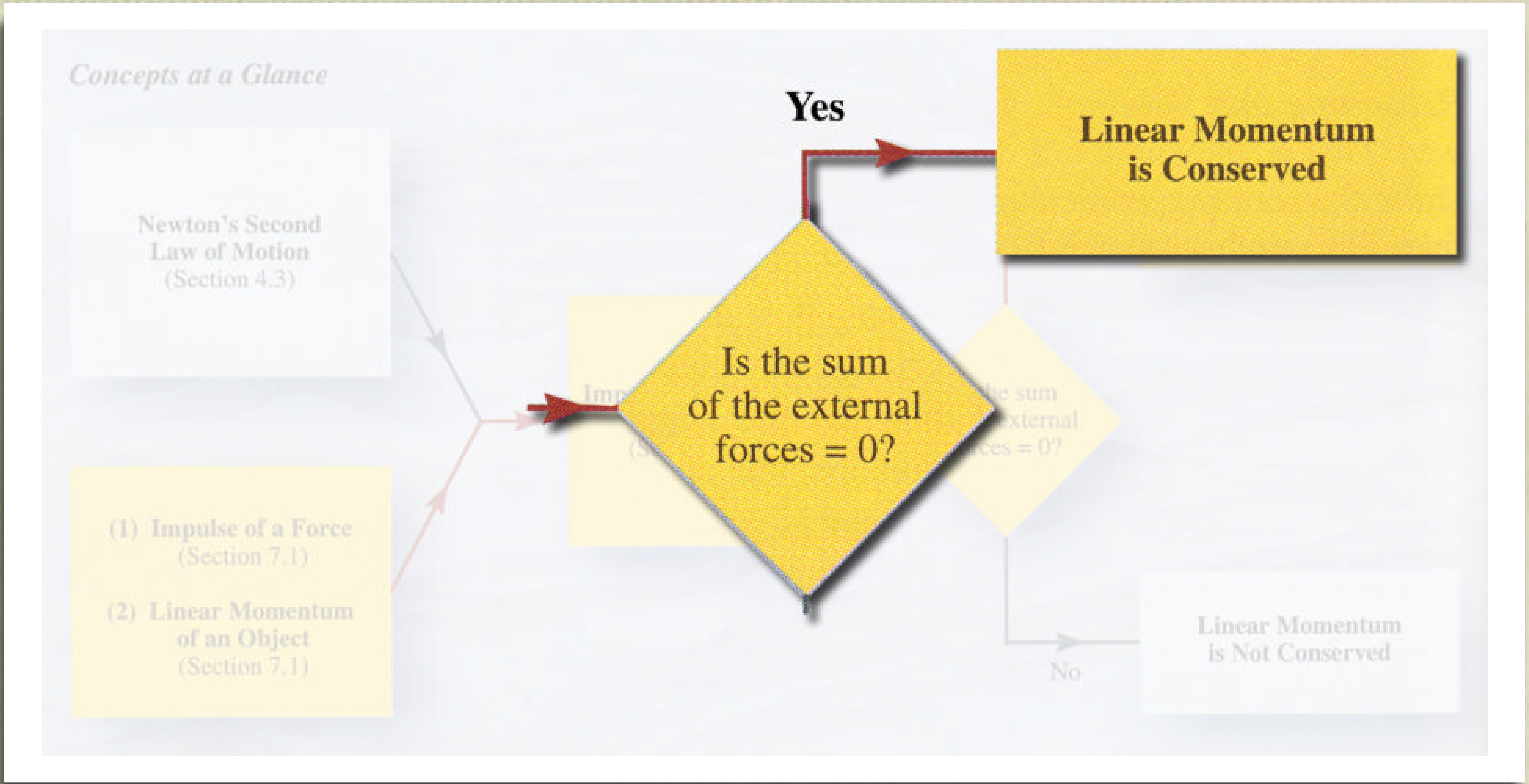

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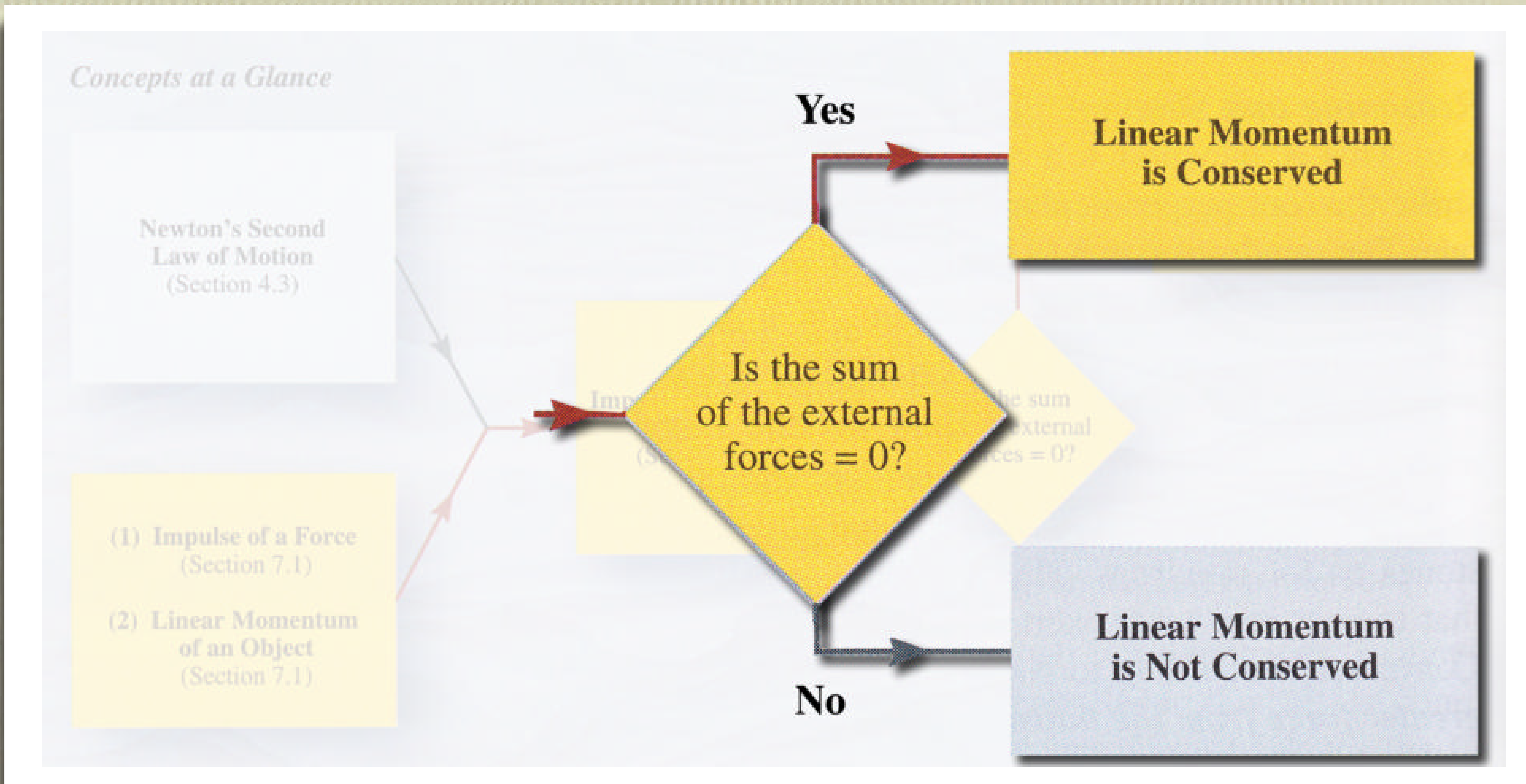

Lack of precision leads to confusion

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.

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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