PS 250: Lecture 29

Wave Energy, Momentum, and Relativity Intro.

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Today's Class

- Wave Energy and Momentum
- Special Relativity
- Summary

Wave Energy Flow

Poynting Vector

- Describes magnitude and direction of energy flow rate in $W/m^2 = J/(s*m^2)$

$$\vec{S} = \frac{1}{\mu_o}\vec{E} \times \vec{B}$$

- Allows calculation of power exiting through any closed surface:

$$P = \oint \vec{S} \cdot d\vec{A}$$

Wave Energy Flow

Average Quantities and Intensity

Average value of S over a sinusoidal wave cycle
(S_{av} = Wave Intensity I)

$$I = S_{av} = \frac{E_{\max} B_{\max}}{2\mu_o} = \frac{E_{\max}}{2\mu_o}\frac{E_{max}}{c} = \frac{E_{\max}^2}{2\mu_o c}$$

Which can also be written as:

$$= \frac{1}{2}\epsilon_o c E_{\max}^2$$

NOTE: Poynting Vector is Instantaneous Vector Quantity
Intensity if Averaged Scalar Quantity

Wave Energy Flow

Average Quantities and Intensity

So, since: $P = \oint \vec{S} \cdot d\vec{A}$

$$P = S_{av} A$$

$$\boxed{\text{Intensity} = S_{av} = \frac{P}{A}}$$

Applicable for simple sinusoidal wave sources that radiate equally in all directions – i.e., in Example Problems.

Wave Momentum

"Radiation Pressure"

Electromagnetic waves apply a "**radiation pressure**" (Force per Area) when they impact a surface:

$$\boxed{p_{\text{rad}} = \frac{S_{av}}{c} = \frac{I}{c}}$$

Pressure on **absorbing** surface.

$$\boxed{p_{\text{rad}} = \frac{2S_{av}}{c} = \frac{2I}{c}}$$

Pressure on **reflecting** surface.

Today's Class

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Einstein's Postulates

Foundation of Special Relativity

- **Principle of relativity:**

  The laws of physics are the same in every inertial (non-accelerating) reference frame.

- **Speed of Light is a Constant:**

  The speed of light in vacuum is the same in all inertial frames of reference and is independent of the motion of the source.

What this implies...

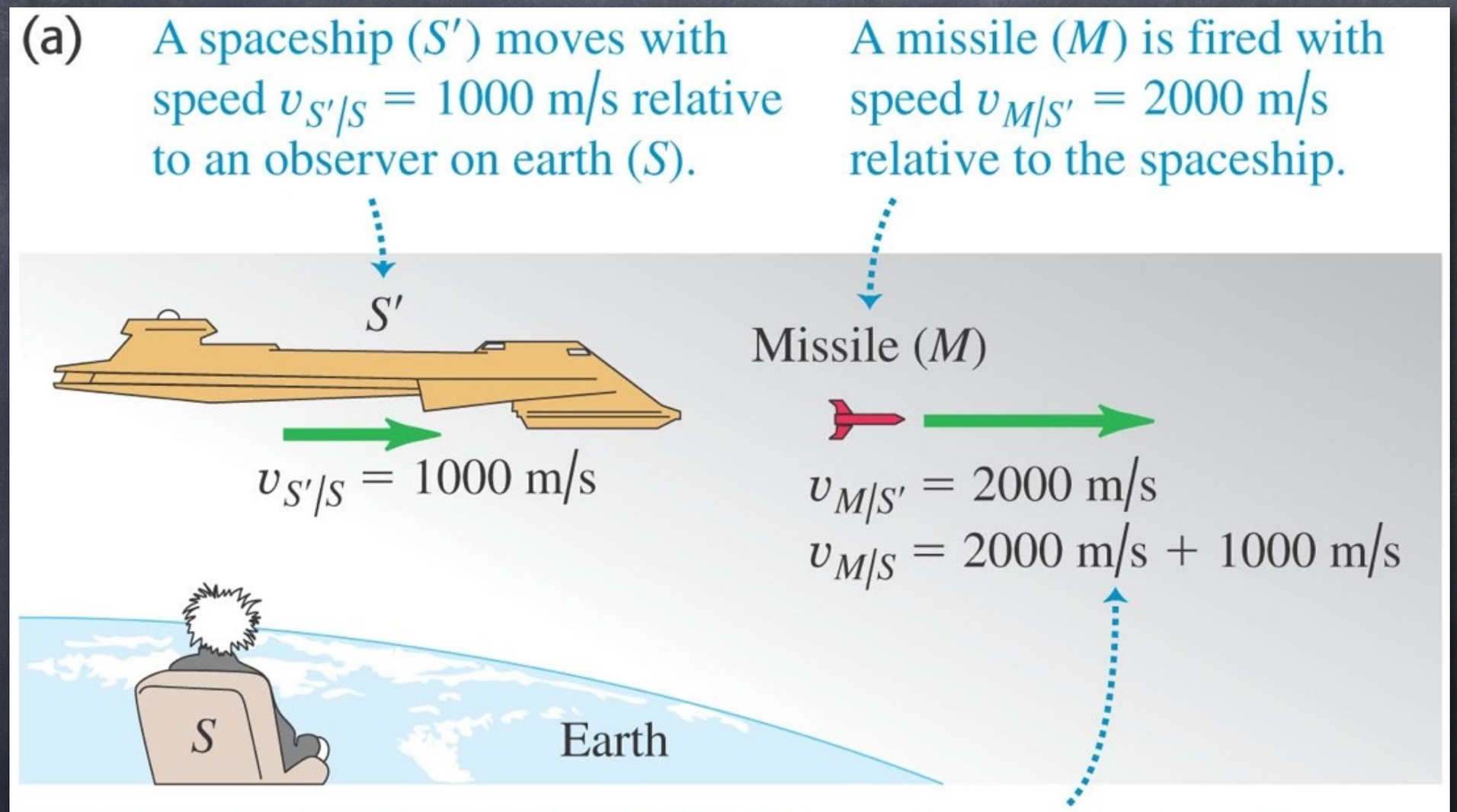
- There is no specific medium that light propagates through - no "ether" - and (in vacuum) it has the same speed in any direction relative to any observer.
- Laws of electro-magnetics apply in any inertial reference frame. (You can move a magnet inside a solenoid to produce an EMF, or a solenoid around a magnet!)
- It is not possible for an observer to travel at the speed of light.

Two Big Conclusions:

Moving clocks run slow.
(Time Dilation)

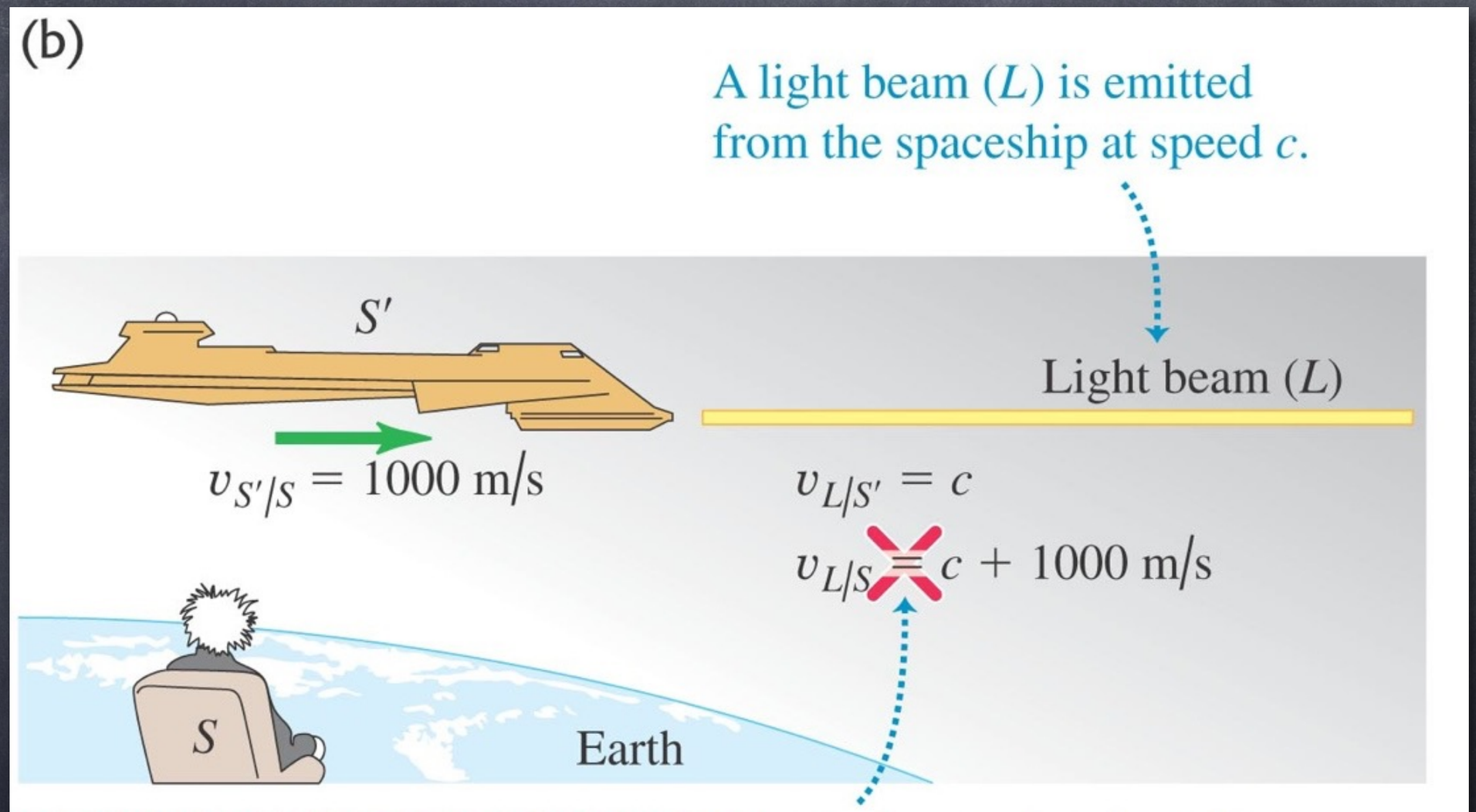
Moving objects are shortened.
(Length Contraction)

Newton vs. Einstein



NEWTONIAN MECHANICS HOLDS: Newtonian mechanics tells us correctly that the missile moves with speed $v_{M/S}$ = 3000 m/s relative to the observer on earth.

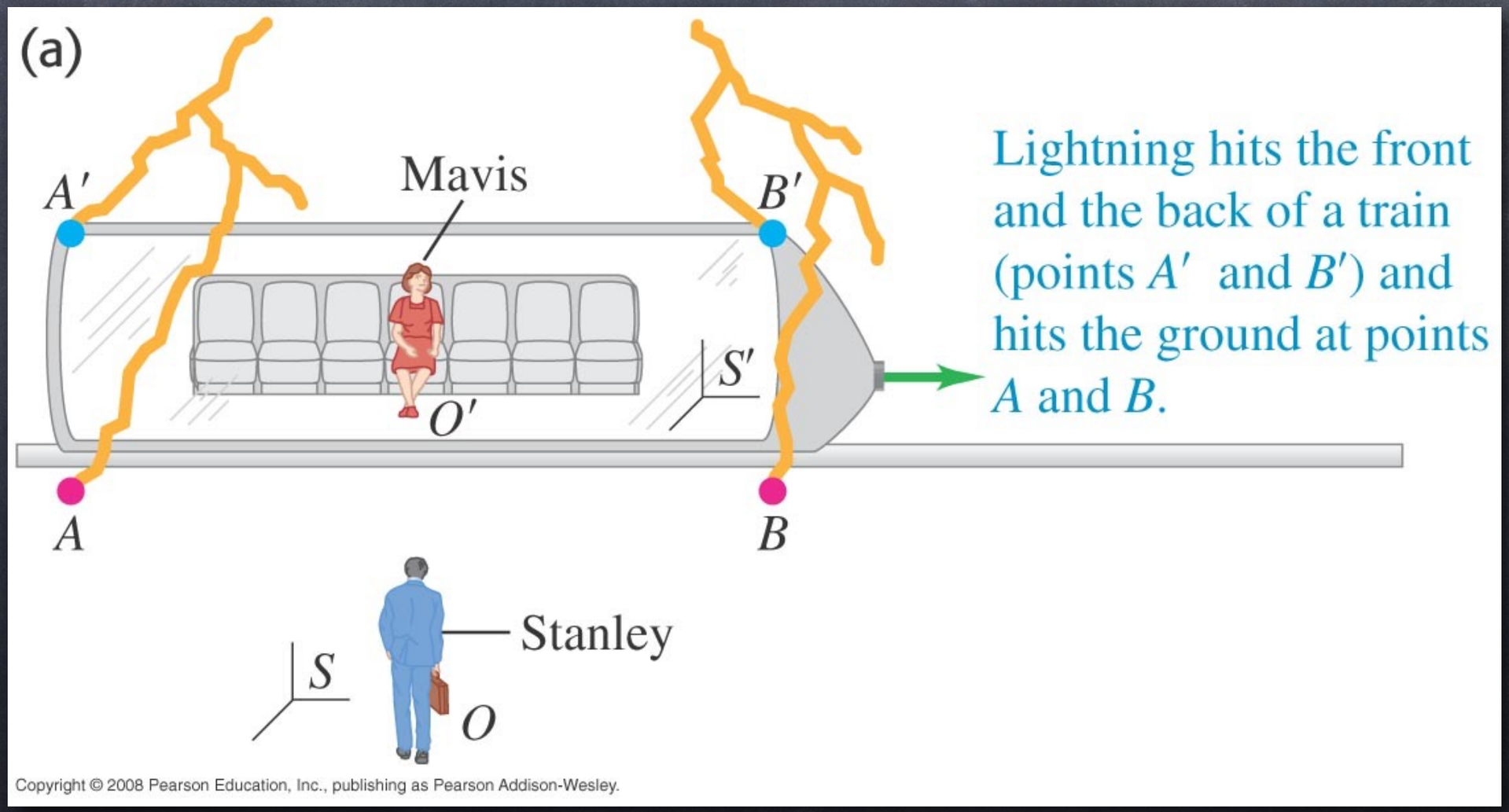
Newton vs. Einstein

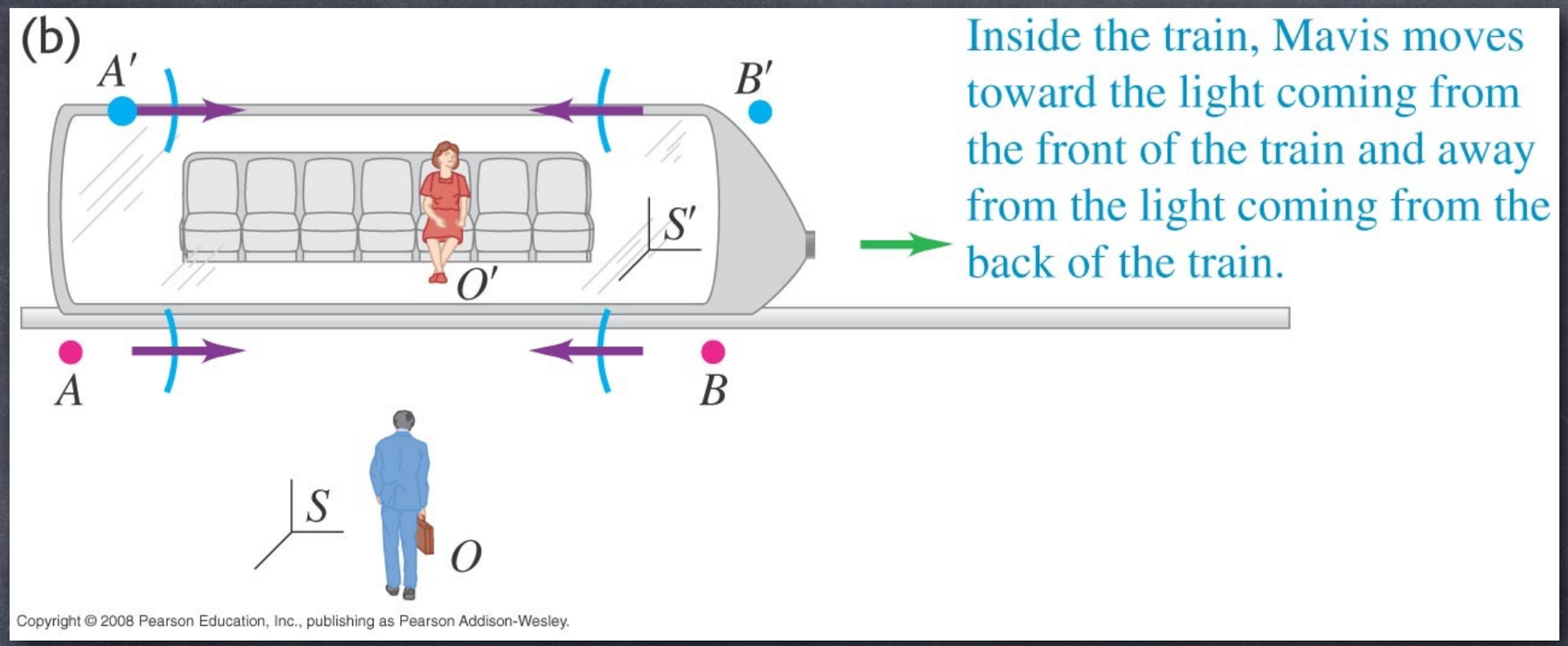


NEWTONIAN MECHANICS FAILS: Newtonian mechanics tells us *incorrectly* that the light moves at a speed greater than c relative to the observer on earth ... which would contradict Einstein's second postulate.

Relativity of Simultaneity

"Two events that are simultaneous in one inertial system are not, in general, simultaneous in another"




(b)
A′
B′
S′
O′
A
B
S
O
Inside the train, Mavis moves toward the light coming from the front of the train and away from the light coming from the back of the train.
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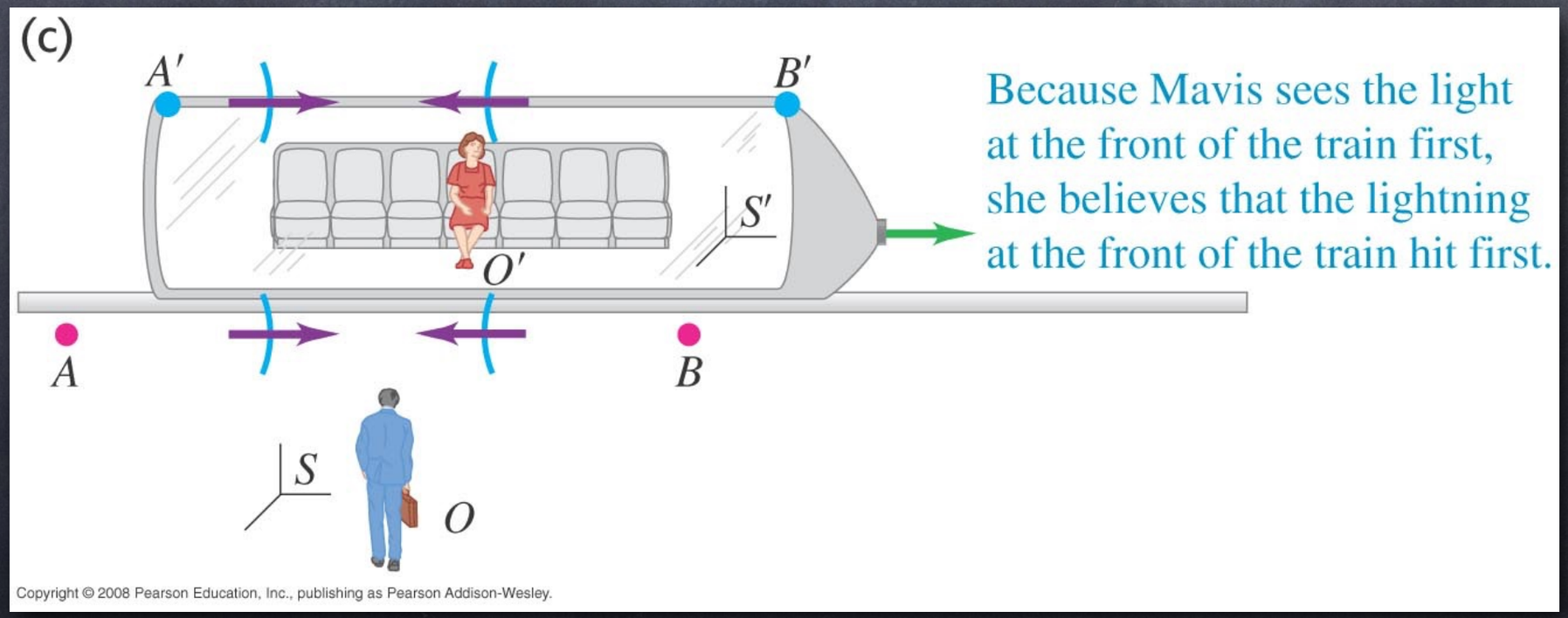
(c)
A′
B′
S′
O′
A
B
S
O
Because Mavis sees the light at the front of the train first, she believes that the lightning at the front of the train hit first.
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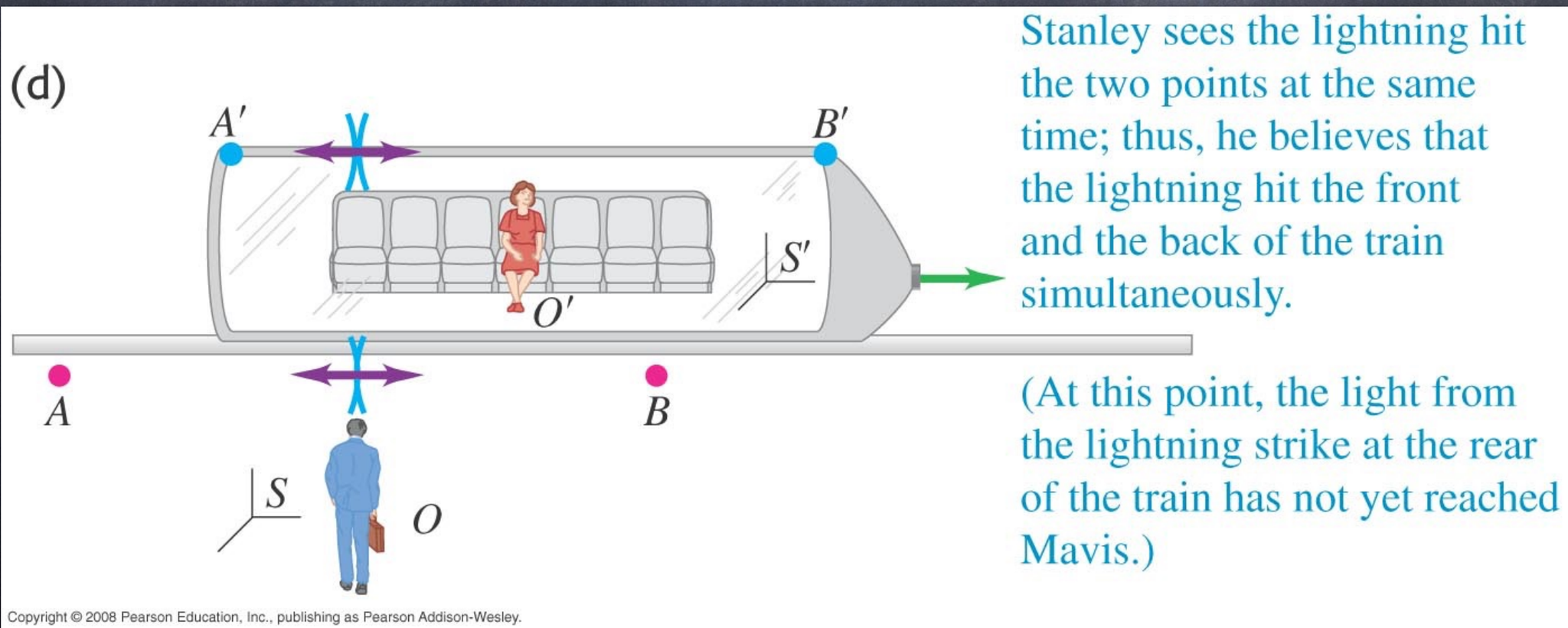
Relativity of Simultaneity

In Mavis' reference frame, the strikes could not have been simultaneous: She is sitting in the middle of the train, and the speed of light is constant!



Summary / Next Class:

- **Mastering Physics** for Today
- **Homework** for Friday