Through the city of Tubingen at nearly the speed of light.

http://www.spacetimetravel.org

Current Assignments ...

Office hours:
3-4 Tuesdays
& Thursdays

For today

- Read Sections 10.5 - 10.6

For Lecture 15

- Read Sections 10.7 - 10.8

Writing Assignment #1

- **Due 11:00 AM, Thursday, February 28 – now!**

Homework #3 (new due date)

- Handed out February 14, due **FRIDAY, MARCH 8**

Suggested Conceptual Exercises

- Chapter 10: 21,25,27,31,35,37,39,41,43,47,49,51

Tutorial #6

- Homework #2 will be returned and discussed

Writing Assignment #2

- Writing Assignment #2 is now available
  - → Posted under Homework on the homepage
- Due **11:00 AM, Thursday, April 4** in the Drop Boxes (late penalty = 5%/day for 1 week)
- Choose a topic in physics that: (i) is related to something we have discussed in the lectures (or will discuss – check the syllabus) and (ii) interests you.
- The essay should be ~4 pages or 1000 words
- Detailed guidelines are given - read them!
- **Avoid plagiarism** (and its penalties)!

Review of Lecture 13

Textbook, Sections 10.1 - 10.4

- Einstein
- Galilean relativity
- The Principle of Relativity
- The speed of light
- The Special Theory of Relativity

Plan for Lecture 14

Textbook, Sections 10.5 - 10.6

- More on the speed of light
- The relativity of time - time dilation
- Time travel

From Lecture 13

The Principle of Relativity

Every nonaccelerated observer observes the same laws of nature.

Principle of Constancy of Lightspeed

The speed of light (and of other electromagnetic radiation) in empty space is the same <u>for all nonaccelerated</u> observers, regardless of the motion of the light source or of the observer.

The Speed of Light

Let's rephrase constancy of the speed of light:

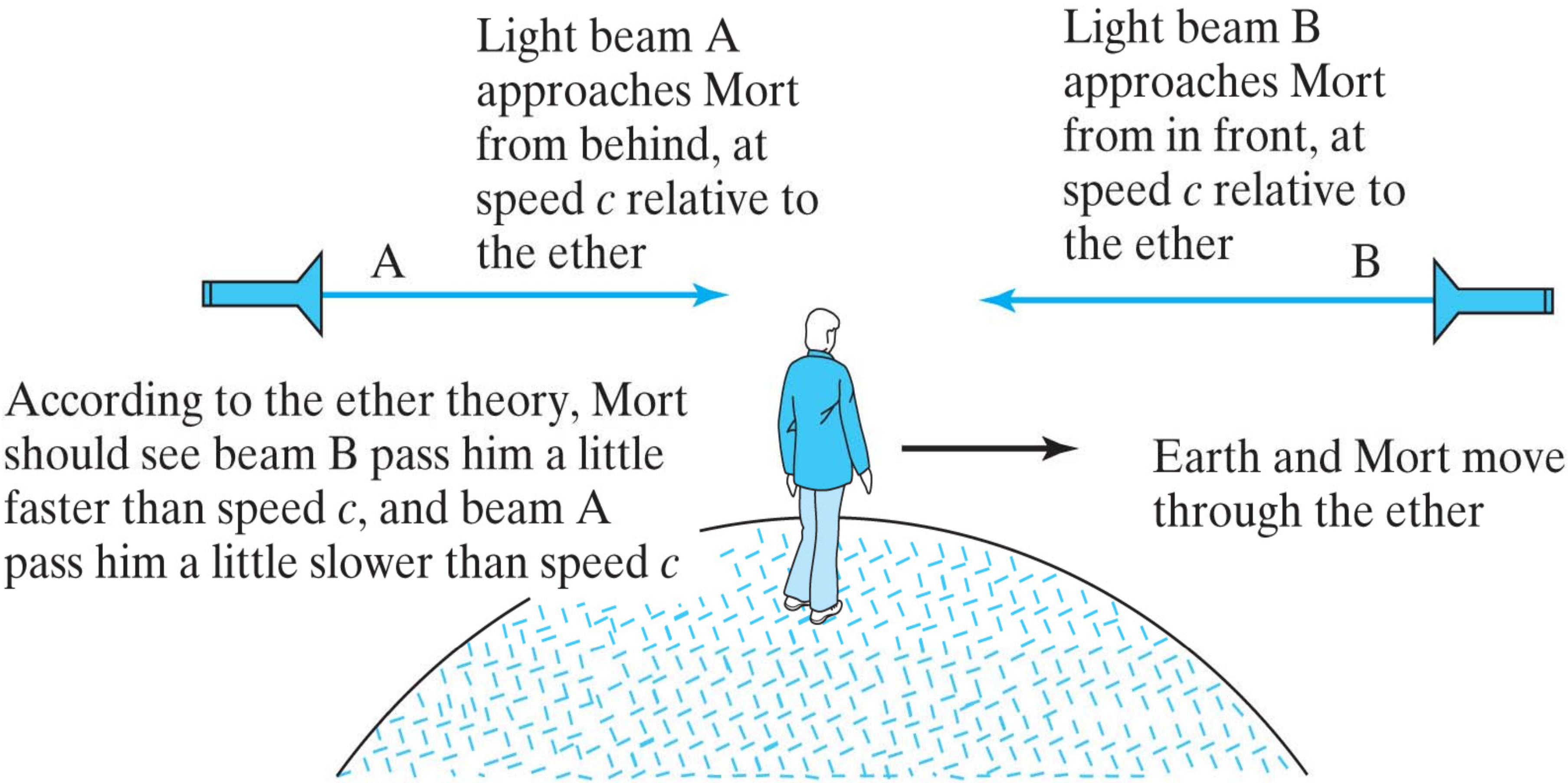
"In every observation of the passage of light from one point to another through empty space, the time taken is simply the relative separation of the points divided by a constant velocity, c."

- This statement explicitly links space and time.
- If c is constant for all observers, then our notions of space and time must depend on the observer...

Michelson Morley Experiment (1887)

- Michelson and Morley invented the interferometer to look for the ether.
  - → Ether was thought to be a medium permeating the universe, through which light moved.
- Since their lab was moving through the ether, they predicted that two light beams moving in different directions would have slightly different speeds relative to the lab. But when they did their experiment:
  - → They found that all beams had the same speed.
  - → This proved that the ether did not exist.
- This experiment also verified the constancy of the speed of light, although this was not believed at the time.

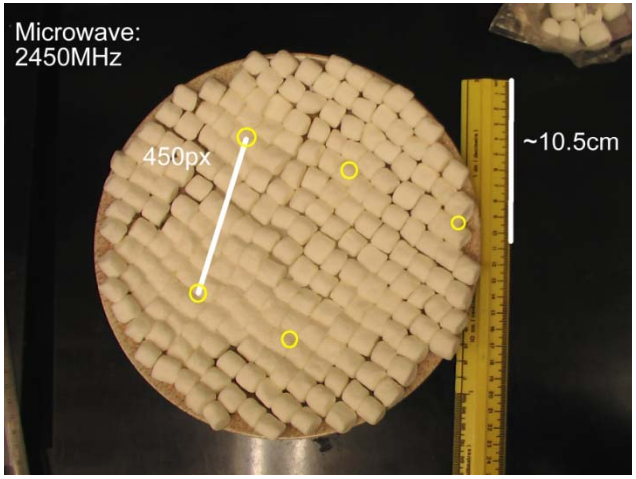
Michelson Morley Experiment



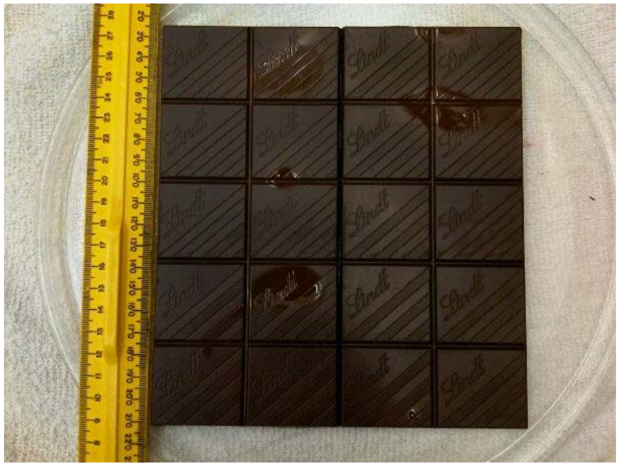
What is the Speed of Light?

Finding the speed of light with marshmallows!

- http://www.physics.umd.edu/ripe/icpe/newsletters/n34/marshmal.htm



- Or with chocolate!



What Is Time?

- Time is something we measure with clocks.
  - → Clocks use some repeating phenomenon to define time.
- Imagine a "light clock".
  - → The mirrors are 150,000 km apart
  - → The light makes a round trip once per second.

A light clock - made of two mirrors and a light beam

Textbook Figure 10.7

What Is Time?

- The speed of light, c = 300,000 km/sec.
- Because the mirrors are 150,000 km apart, it takes one second for the light to travel back and forth (one complete round trip).
- Let the light clock "tick" at the end of each round trip.
- Now let's do a thought experiment using two light clocks.
  - → One on Velma's spaceship
  - → One with Mort on Earth

What does Mort see when Velma flies past him?

Textbook Figure 10.8

He sees her light beam traveling farther than his between "ticks".

Mort sees Velma's clock run slow.

What does Velma see as she flies past Mort?

Textbook Figure 10.8

She sees his light beam traveling farther than hers between “ticks”.

Velma sees Mort’s clock run <u>slow</u>.

Who is correct?

- Answer: They are both correct!
- There is no correct observer and no truly universal time.

Rule: Moving clocks run slow.

- Time is relative – it depends on the relative speed of the clock and the observer.
- Any phenomenon that varies with time will exhibit the same behavior as the clocks e.g., aging animals, melting ice

Time Dilation

- We can show that time measured by a moving clock is slow, or “dilated”, according to the equation:

$$T = \frac{T_o}{\sqrt{(1 - v^2/c^2)}}$$

where

- T is time in the moving frame of reference (e.g., Velma’s as seen by Mort)
- T_o is time in the stationary frame of reference (e.g., Velma’s as seen by Velma)
- v is the relative speed (e.g, between Mort and Velma)

Time Dilation

So we have time T measured by a clock moving at speed v running slow, or “dilated” compared to the time T_o measured by a stationary clock:

$$T = \frac{T_o}{\sqrt{(1 - v^2/c^2)}}$$

We can also write this as: $T = \gamma T_o$

where

$$\gamma = \frac{1}{\sqrt{(1 - v^2/c^2)}} > 1$$

so $T > T_o$

Some Points to Note

(1) The time difference between two events is always shortest in the reference frame for which the events occur at the same place.

(2) The time measured in this reference frame is called the proper time (= the shortest time).

(3) Time dilation does not depend on the direction of motion of the reference frame (v).

(4) Time dilation is symmetric. We don't really want to say that reference frame A' is in motion, as we don't know if A or A' is in motion.

(5) The only way to apply time dilation is if you have two events that happen at the same PLACE in one reference frame.

e.g., Clock (this is why clocks are so often used - because we assume that the clock remains sitting in the same place in the reference frame!)

The Relativity of Time

Textbook
Table 10.1

The Relativity of Time

Textbook
Figure 10.9

Figure 10.9

This graph shows the duration of one clock tick (representing 1 second in the clock's reference frame) on a moving clock, for various speeds of the clock relative to the observer.

Concept Check 6

Mort and Velma have identical ice cream cones that melt in 10 minutes. Velma passes Mort at 75% of lightspeed. How long does Mort say it takes the two cones to melt?

	Mort's	Velma's
(A)	10 minutes,	10 minutes
(B)	10.3 minutes,	10 minutes
(C)	10 minutes,	10.3 minutes
(D)	15 minutes,	10 minutes
(E)	10 minutes,	15 minutes

The time dilation factor is 1.5 for 75% of lightspeed.

How about those frogs?

Mort and Velma have identical frogs who live for 10 days. Velma passes Mort at 75% of lightspeed. How long are the frogs' lifetimes <u>according to Mort</u>?

	Mort's	Velma's
(A)	10 days	10 days
(B)	10 days	15 days
(C)	15 days	10 days

How about those frogs?

Mort and Velma have identical frogs who live for 10 days. Velma passes Mort at 75% of lightspeed. How long are the frogs' lifetimes according to Velma?

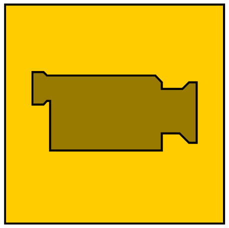
	Mort's	Velma's
(A)	10 days	10 days
(B)	10 days	15 days
(C)	15 days	10 days

So Mort sees his frog die first and Velma sees her frog die first. Both are correct!

Time Dilation Animation

Try this at home yourself:

- http://www.upscale.utoronto.ca/GeneralInterest/Harrison/SpecRel/Flash/TimeDilation.html



How fast do Mort and Velma age?

- If Velma passes Mort at 75% of lightspeed, then
  - → Mort and his descendants see Velma age 120 years during his 80-year lifetime.
    - She lives for 120 years as measured by Mort's clock.
    - He sees her age slowly, by 1 yr for each of his 1.5 yrs.
    - He dies after 80 of his years and she dies after 120 of Mort's years, but she looks like an 80-year-old.
  - → Velma and her descendants see Mort age 120 years during her 80-year lifetime.
  - → And both are correct!
- Each will see the other age more slowly.