DAY 22

Summary of Topics Covered in Today's Lecture

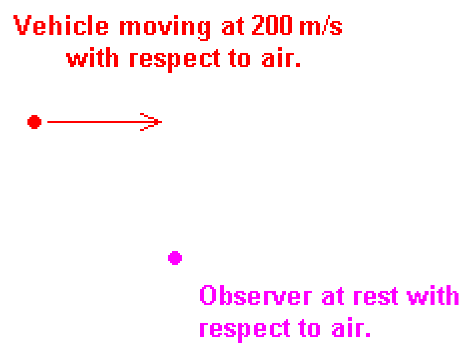
The Speed of EM Waves is a Constant

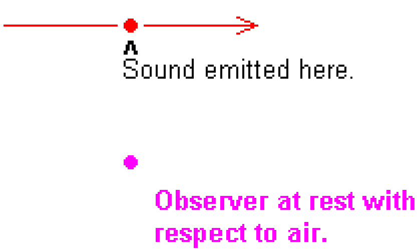
Albert Einstein came up with this solution to the aether question. He said that there was no aether – that EM waves (such as light) travel at $v = 3.0 \times 10^8$ m/s as seen by all observers. Since this is a universal **c**onstant it is often written

$$c = 3.0 \times 10^8 \text{ m/s}$$

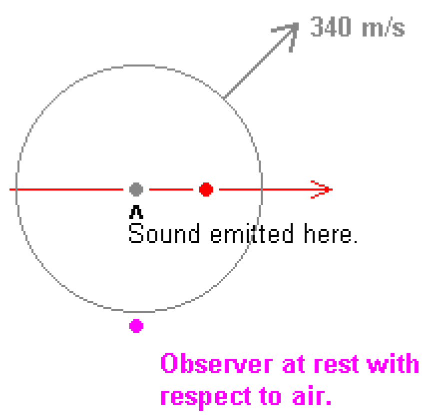
This was a very different sort of idea. Let's compare what this means for light waves to the behavior of sound waves.

Imagine that there is a vehicle moving at a speed of 200 m/s through air (red dot in the figure at right). The air is the medium for sound waves. There is also an observer (purple dot) who is at rest with respect to air. The vehicle is moving at 200 m/s with respect to the observer, too.

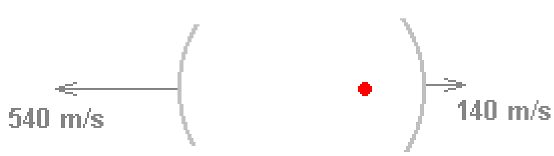




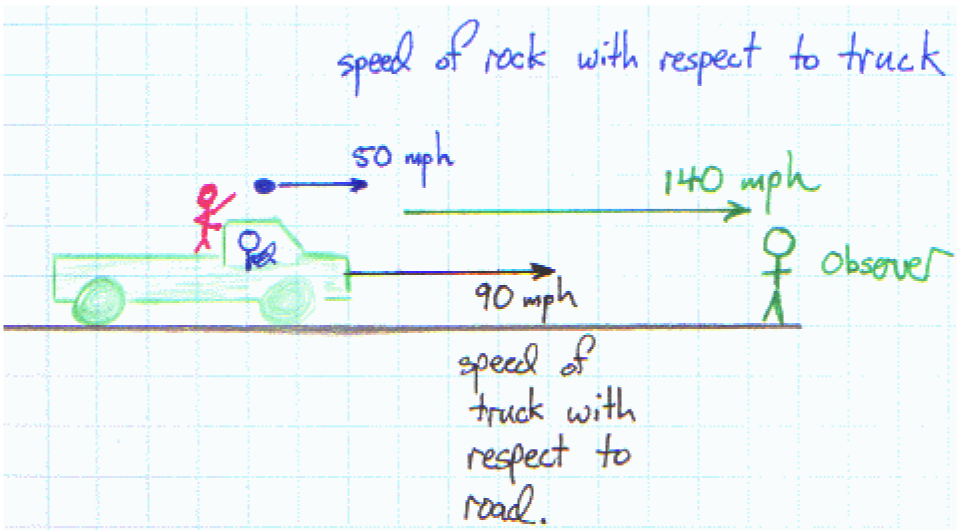
When the vehicle gets to the location shown at left, it emits a sound pulse. The sound waves travel out from the point of emission at 340 m/s as shown below.



However, from the point of view of the vehicle, it is at rest. The air is rushing by at 200 m/s. The sound wave in front of it is moving away at 340 – 200 = 140 m/s, while the sound wave to behind it is moving away at 340 + 200 = 540 m/s.



This view of being at rest with the air rushing past and the sound wave moving away is perfectly valid. To use another example, imagine a truck moving down a road at 90 mph. A person in the back of the truck throws a rock forward at a speed of 50 mph. To the driver of the truck, the rock is moving at 50 mph. But to an observer standing on the road, the rock moves at 140 mph. Both 50 mph and 140 mph are "correct" speeds for the rock. It is not the case that one is right and the other is wrong.



The driver and observer differ on their measurements of the speed of the rock, but they do not differ in their understanding of the laws of physics. For instance, they both agree the rock will keep moving at constant speed in a straight line unless acted on by an outside force. When factoring in gravity but neglecting air friction, they will both expect the rock to travel in a parabolic arc. They will both use the same equations to include the effects of air friction in determining the rock's motion. This idea that, while the exact details of a problem are dependent on (or *relative* to) the observer in question, **the laws of physics are the same for both** is a concept that has been understood since Galileo and Newton, and is called Galilean or Newtonian Relativity.

This applies only in the case of observers moving at constant velocity. Such observers are obeying Newton's 1st Law of motion – the Law of Inertia that says an object in motion remains in motion. Thus we say this form of Relativity applies for *inertial frames of reference*. If the observers are accelerating then they are not in an inertial frame of reference and things get a lot more complex.

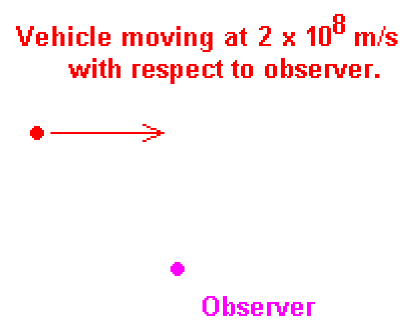
To summarize: **Galilean-Newtonian Relativity says that the laws of physics are the same for all observers in inertial frames of reference. Such observers may disagree on the specifics of a system, but will agree on the laws of physics that apply to the system.**

Einstein modifies this only slightly for what is called his *Special Theory of Relativity*. Einstein says:

1) **The laws of physics are the same for all observers in inertial frames of reference. Such observers may disagree on the specifics of a system, but will agree on the laws of physics that apply to the system.**

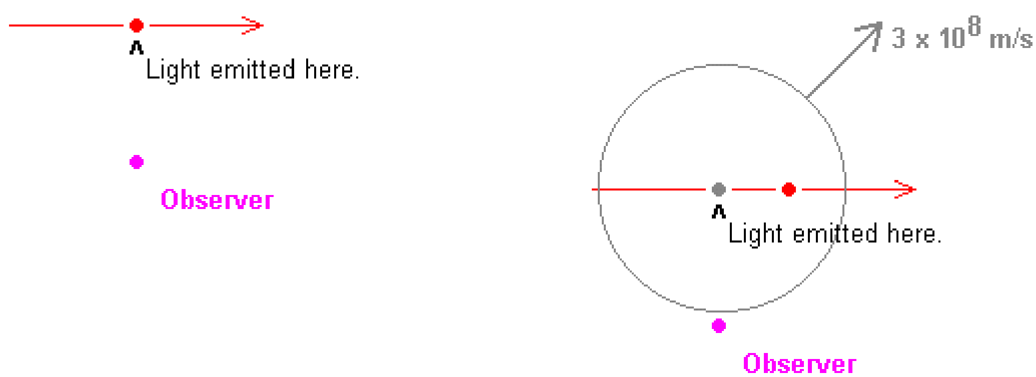
and furthermore

2) **All observers in inertial reference frames will also agree that light moves at the same constant velocity (namely $c = 3.0 \times 10^8$ m/s) regardless of how they may be moving.**



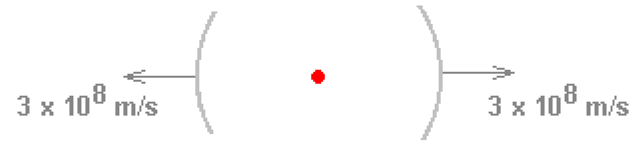
Now imagine that there is a vehicle moving at a speed of 2×10^8 m/s relative to an observer. There is no aether for EM waves so there is no medium for the observer to be at rest with respect to.

When the vehicle gets to the location shown, it emits a light pulse. The light waves travel out from that the point of emission at a speed of 3.0×10^8 m/s.



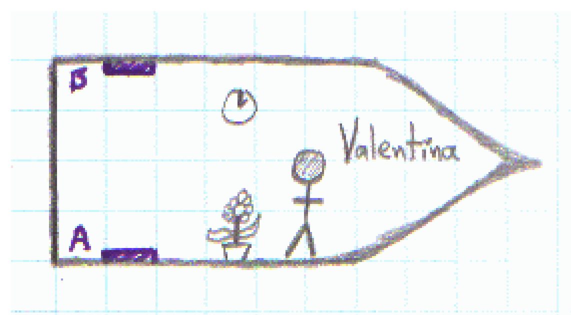
However, from the point of view of the vehicle, it is at rest. Period. The purple observer moves by at 2×10^8 m/s but so what?

What does that have to do with the light pulse it emitted? There's no medium rushing by. The light pulse moves off in all directions at 3×10^8 m/s.



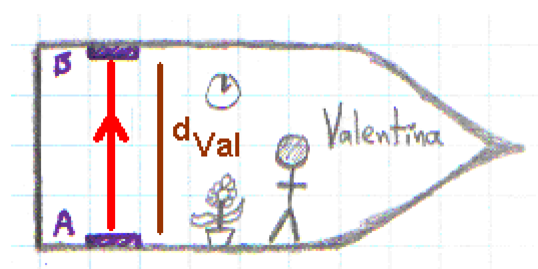
Similarly, imagine a truck moving down a road at 90% of *c*. A person in the back of the truck shines a light forward – the light moves at speed *c*. To the driver of the truck, the light moves at *c*. But to an observer standing on the road, the light moves at speed *c*. If the light was like the rock in the previous example, we might expect the observer on the road to see the light moving at 190% of *c*, but no. **All observers see light as traveling at c = 3.0×10^8 m/s no matter what.**

This has some odd consequences. For example, suppose that a space traveler, Valentina, has a clock on board her ship that measures time by bouncing a laser between two parallel mirrors at A & B.

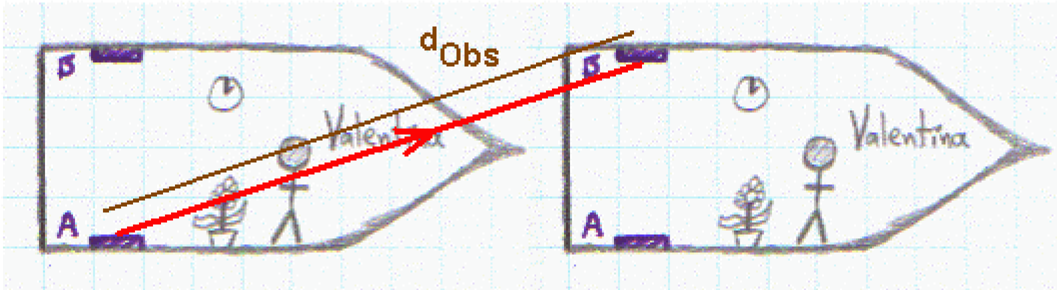


Thus each trip of the laser corresponds to a certain time interval on the ship – a certain number of seconds, a certain number of beats of Valentina's heart, a certain amount of aging of Valentina's body, a certain amount of growth in Valentina's on-board garden. That time interval (t_{Val}) is just the distance between the mirrors divided by the speed of the laser (*c*).

$$t_{Val} = \frac{d_{Val}}{c}$$



So the laser going from A to B takes time t_{Val} as seen by Valentina. But what about an outside observer? An outside observer who sees Valentina's ship moving to the right will see this:



Because the ship is moving, the path the light takes in going from A to B is longer than just the vertical distance from A to B. The time it takes the laser to go from A to B as seen by the outside observer (t_{Obs}) is again just the distance the observer measures divided by the speed of the laser.

$$t_{Obs} = \frac{d_{Obs}}{c}$$

However, since d_{Obs} is longer than d_{Val}, while c is the same for both, we get the result that

$$d_{Obs} > d_{Val}$$
$$ct_{Obs} > ct_{Val}$$
$$t_{Obs} > t_{Val}$$

Therefore the observer sees this event taking a longer time than Valentina does. Since all time on the ship can be measured by this simple event, any event on the ship takes longer as seen by the observer. If, for example, $d_{Obs} = 2\ d_{Val}$, then if Valentina sees one year pass, the observer will see two years pass. Thus an observer will age more rapidly than Valentina. Time runs at different rates for Valentina and the observer!