Relativity in the rough

Source: http://sci.tech−archive.net/Archive/sci.physics/2005−03/1078.html

---

From: Alan Boyle (*alan.boyle_at_msnbc.com*)
Date: 03/01/05

```
Date: Tue, 1 Mar 2005 11:24:57 −0800
```

Howdy to the group: I'm Alan Boyle, science editor at MSNBC.com... We're in the midst of putting together a graphic introduction to relativity in honor of the Einstein centenary, and I thought I would try to put out a first rough draft of the "script" so that if there are glaring problems, we can fix them *before* we do all the Flash magic and publish it. This is just a rough outline, and there may be incomplete references to things that would be included in the app... but if you see anything glaringly miscast, please write alan.boyle@msnbc.comBUTNOSPAM ... Probably should put "Rough Relativity" in the subject line so I can distinguish it from the Nigerian investment opportunities. Many thanks...

The roots of relativity

I. Introduction: Einstein's relativity theories predict some weird effects, such as black holes, a kind of time travel and bending light waves. But Einstein didn't go out looking for the weirdness; rather, the grand achievement of his theories was to demonstrate that the laws of physics work the way we think they should, even in weird circumstances. Einstein's view of the world is actually the one that best fits our everyday experience. Click through this graphic to find out why.

II. Before Einstein.

a. Galilean relativity: The idea of relativity goes back to Galileo's day in the mid−1500s. If you're playing a game of tennis on the deck of a smoothly sailing cruise ship, would you have to change your game completely just because you're traveling across a calm ocean at 25 mph? Of course not. That illustrates the Galilean concept of relativity, that the laws of physics work equally well in any reference frame, even if one frame is moving with respect to another frame. By adding together forces and velocities, you could figure out exactly how that tennis ball would move, on land or on the cruise ship.

b. The problem of electrodynamics: What about light waves? In the mid−1800s, physicist James Clark Maxwell determined that electromagnetism − including electricity, magnetism and even light − propagated through space as waves. These waves were thought to ripple through a substance that filled the universe, known as the ether, just as sound waves propagated though air.

That implied that the speed of those electromagnetic waves through a vacuum* would vary, depending on whether you were at rest with respect to the ether, or moving through the ether, just as the speed of sound waves varied. And that, in turn, implied that not all reference frames would be the same when it came to light and other electromagnetic waves. Physicists conducted increasingly precise experiments to look for variations in the speed of light that could reveal how fast Earth was moving through this universal ether − but every time they looked, the speed of light was exactly the same. (Climax came with the 1887 Michelson−Morley experiment, one of the most famous experiments in physics)

(* When we're talking about speed of light, we're always talking about its maximum speed in a vacuum. Light waves can always move more slowly in a medium such as water or glass. In fact, physicists have designed some ultra−cold environments where light seems to stop altogether.)

III. Special relativity: Clocks and yardsticks

a. Einstein instinctively knew there was something wrong with the way physicists were thinking about the problem. Even at the age of 16, he daydreamed about matching the speed of a light wave and seeing it frozen in space. Such an idea would lead to bizarre effects: For example, if you held a mirror in front of your face, the light reflected from your face could never catch up with the mirror, meaning the glass would be blank.

b. A decade later, in 1905, Einstein put forth the claim that electromagnetic waves obeyed the same principle of relativity Galileo put forth for the motion of objects more than three centuries earlier: The laws of physics are the same in all smoothly moving reference fields. Einstein said that also meant that the speed of light was constant, even if that idea might seem "apparently irreconcilable" with the principle of relativity.

c. How did Einstein reconcile those two ideas? He made the radical assertion that because the speed of light the same in all reference frames, it must be our measurements of distance and time that vary between reference frames.

d. Light clock illustration:

1. Set up Al's light clock: Box with a light pulse flashing up and down, and a counter for each beat. A

2. Set up Bert's light clock: Moving with respect to the first.

3. Pre−Einsteinian view: Light pulse moves up and down at the same beat. But since the light pulse takes a diagonal path for Bert's clock, it has to move faster to keep the same beat. More than a century's worth of experiments, however, have shown that this isn't the case. (Poof!)

4. Einsteinian view: Light pulse moves at a constant speed, meaning that it appears slower for Bert's clock. (2 or 3 beats for Bert's clock, 4

beats for Al's clock)

5. It gets even stranger: We've shown that from Al's point of view, Bert's clock seems to be ticking more slowly. But from Bert's point of view, it's Al's clock that's the slow one.

e. This phenomenon has sparked the phrase "moving clocks run slow" . but physicists say that phrase can be misleading. As we've just seen, either Al's or Bert's clock could be considered the "moving" clock. Physicist Richard Wolfson suggests a more "relative" description of the relativity in time measurement: "The time between two events is shorter when measured by a single clock that's present at both events than it is when measured by two separate clocks."

f. And if time gets "squishy" between reference frames that are moving with respect to each other, measurements of distance gets squishy also. It turns out that your measurements of objects that are moving through your reference frame get shorter in the direction of the motion. (Shrinking yardstick.)

g. Al and Bert twin−paradox calculator (* The fact that Al ages more than Bert might seem to contradict relativity theory. From Al's point of view, shouldn't it equally be the case that Bert would seem younger? No: The reason Al's the one who ages more slowly is because he's in a shifting reference frame. For an alternate explanation, stay tuned for general relativity.)

h. One of the implications of the theory is that it would be impossible for an object to be accelerated all the way up to the speed of light. If you were to measure the dimensions of an object moving at 99.999999 percent of the speed of light, relative to your reference frame, that moving light clock would slow to a near−stop, the object would seem to shrink to near−nothingness, but its measured mass would come close to infinity. It would take an infinite amount of energy to give the object that extra little push to light speed − which is the root of Einstein's most famous equation, E=mc2.

i. All this can get confusing: Observers in different frames of reference might not agree on what happens when, or even which events come first and which come later. (Mishmash of moving clocks, yardsticks, trains, rocket ships, etc., on overlapping grids.) So does that mean that everything's relative? Are we lost in space and time? Thankfully, no. Einstein's special theory of relativity includes equations that help physicists work out consistent coordinates for events, using measurements that incorporate space as well as time − a four−dimensional view of the cosmos known as spacetime. (Grids shift to align the patterns of clocks, etc., into one picture that points the way to the next section on "warps in spacetime".)

IV. General relativity: Warps in spacetime

a. In the world of clocks and yardsticks, we've been talking about reference frames that move uniformly in relation to each other. But that's actually a very rare and special scenario − that's why the theory is called "special" relativity. Einstein realized that if he was going to have a coherent explanation for how the electromagnetic realm worked, he'd have to account for scenarios in which there was acceleration, including the force of gravity. And that meant he'd have to take on an even bigger challenge: the Newtonian view of the universe.

b. Problem for Einstein: Newton's claims that there was an "absolute time," and that gravity acted instantaneously on distant objects. Both those claims contradict special relativity.

c. In 1907, Einstein had what he later called the "happiest thought in my life": that gravity and powered acceleration were equivalent for any local reference frame. Nine years later, the insight yielded what is now known as the general theory of relativity, Einstein's crowning achievement.

d. In thinking about the Principle of Equivalence, Einstein visualized the experience of a man falling off a roof. But for our purposes, let's consider a sealed elevator car in Earth's gravity field, as well as a rocket ship in zero−gravity:

1. Elevator car in free fall (left) (Newton in the left car, Einstein in the right)

2. Rocket ship in zero−gravity (right)

3. Elevator car comes to rest (left)

4. Rocket ship accelerates at 32 ft/sec2 (right)

5. Laser light (another Einstein−based innovation) turns on in rocket ship (right)

6. Lantern with focused beam turns on in elevator car (left)

7. Conclusion: Light bends in a gravity field! (Einstein smiles, Newton frowns)

e. Newton's theories did not account for the bending of light waves, which have no mass. The bending of light led Einstein to propose that gravity was not a mysterious "action−at−a−distance" force that acted on mass. Rather, gravity arose from the way concentrations of mass warped the fabric of spacetime itself, and objects as well as light waves simply followed the path of least resistance through those warps. Physicist Richard Wolfson calls this a case of "cosmic laziness."

f. The greater the mass, the more curvature there is. One way to measure that curvature would be to have a setup of three powerful lasers and light sensors around a huge star. If the star is relatively light, the angles of this cosmic triangle would add up to about 180 degrees. The more massive it is, the higher the sum would be. Add or subtract mass to this star to see how space curves. (The ball−on−rubber−sheet model. In the extreme case of a black hole, the sum would go up to 1,080 degrees . three times 360.)

g. Remember how outside observations of time and space vary between reference frames that are in smooth motion with respect to each other? This effect applies to accelerated reference frames as well. For example, if you were to send a clock and a yardstick from Earth to Jupiter, the clock would seem to tick slower and the yardstick would shrink slightly in the stronger gravitational field. When the clock was brought back to Earth, it would still be out of sync. That provides an alternate explanation for the phenomenon in the twin paradox: Al is the one who goes through acceleration and deceleration, while Bert isn't subjected to as many forces during Al's trip. Thus, Al is the one who ages less.

V. Proving Einstein right: At first, Einstein's theories weren't given much credence. But as years and decades went by, the evidence in support of those theories grew − and believe it or not, scientists would find it hard to function without them. Here are some of the key phenomena confirming the theories:

a. Precession of Mercury (check)

b. Bending of light during eclipse (check)

c. Subatomic particle decay and E=mc2 (check)

d. Spacetime frame dragging (check) . including GPS (cf. Scientific American): GPS satellites have to be adjusted by 38 microseconds every day to account for the relativity effect.

e. Black holes (semi−check)

f. Gravity waves (question mark)

Sources: "Simply Einstein" by Richard Wolfson; "Einstein for Beginners" by Joseph Schwartz and Michael McGuinness; Scientific American; Physics FAQ