[This course deals w/
two revolutions in physics that occurred
at the beginning of the 20th century:
quantum mechanics & special relativity.

The dates almost perfectly align w the beginning of the century.

Max Planck initiated quantum mechanics in the paper
in which he introduced his famous constant in 1900.
Five years later, Albert Einstein unleashed special
relativity in his 1905 paper on electrodynamics of
moving bodies.
He also published a paper that year on the
quantization of electromagnetic waves,
which we now refer to as photons.]

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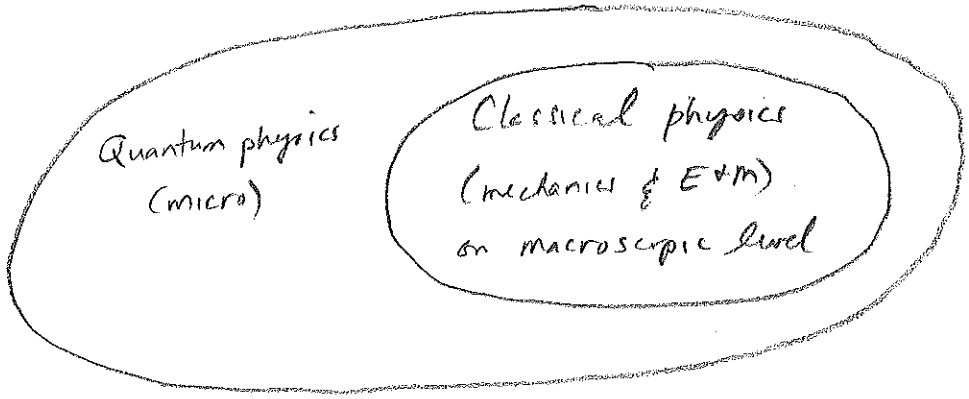
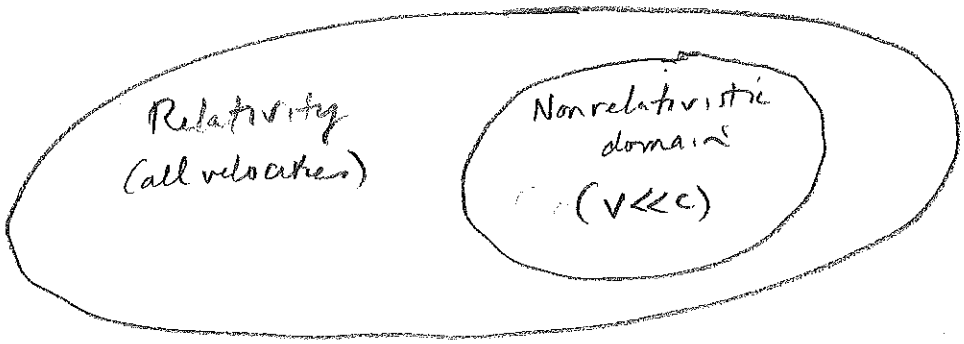
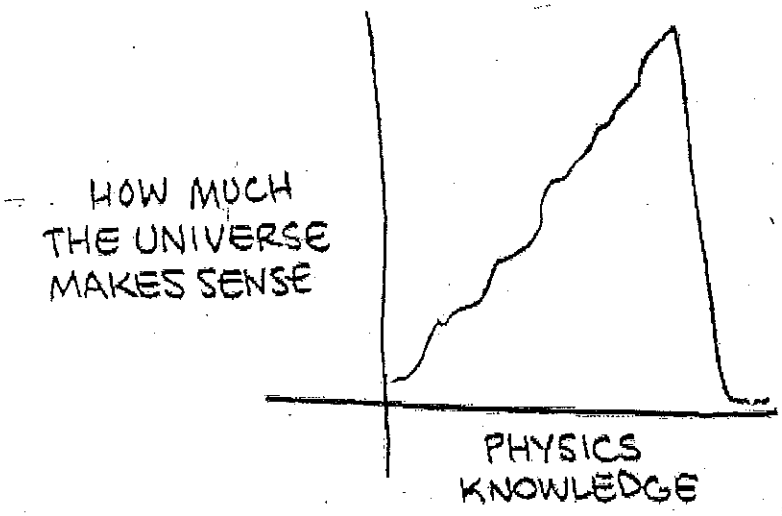
[But these were not revolutions in the traditional sense that they wiped away preceding understandings of physics. Rather they subsumed them as limiting cases.]





[Every successful theory swallows its predecessors alive.]

[These new theories have one thing in common.
Both regarded as confusing and counter intuitive.
In this course, we try to rebuild your intuitions.]

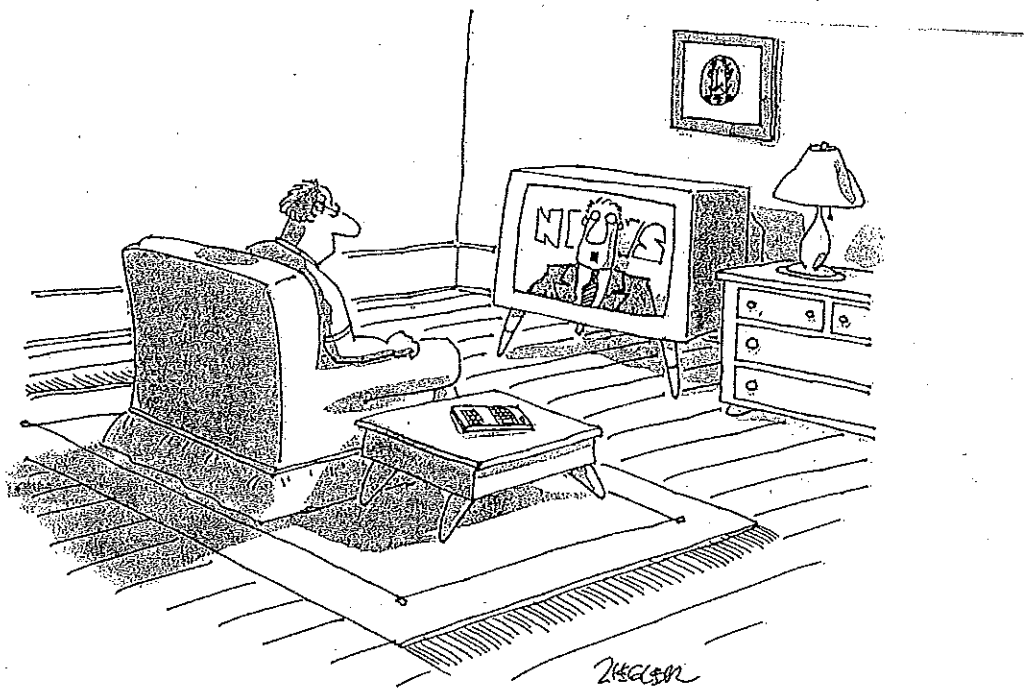


Nature and nature's laws lay hid in night;
God said, "Let Newton be!" and all was light.

–Alexander Pope

It did not last; the devil, howling "Ho!
Let Einstein be!" restored the status quo.

–unknown



"Scientists confirmed today that everything we know about the structure of the universe is wrongedy-wrong-wrong."

PRINCIPLE OF RELATIVITY

[Although widely associated with Einstein,
the principle of relativity goes back to Galileo.
Refers to the relativity of motion.
There is no state of]

~~ABSOLUTE REST~~

[and no notion of]

~~ABSOLUTE MOTION~~

VELOCITY IS RELATIVE.

[The velocity of an object only has meaning
when defined w.r.t. some other object,
or, if you like, w.r.t. some reference frame.
More to say about reference frames later.

An object may be at rest in one ref. frame (car)
but at some time in motion in another (road).

That may seem pretty trivial, even obvious.]

[What is not obvious is that
from point of view of the laws of physics,
all inertial reference frames are equivalent.
Laws of physics are the same in any IRF.

If I am moving with respect to you,
things behave same wrong in my frame
as they do in yours. Not so obvious in a moving car but more so in a plane.
Therefore cannot conduct any experiment to
determine whether I am moving and you are at rest
or whether you are moving and I am at rest.]

‡Galileo Galilei, *Dialogue Concerning the Two Chief World Systems—Ptolemaic and Copernican*, first published February 1632; the translation quoted here is by Stillman Drake (University of California Press, Berkeley, 1962), pages 186ff. Galileo's writings, along with those of Dante, by reason of their strength and aptness, are treasures of human thought, studied today in Italy by secondary school students as part of a great literary heritage.

SALVATIUS: Shut yourself up with some friend in the main cabin below decks on some large ship, and have with you there some flies, butterflies, and other small flying animals. Have a large bowl of water with some fish in it; hang up a bottle that empties drop by drop into a wide vessel beneath it. With the ship standing still, observe carefully how the little animals fly with equal speed to all sides of the cabin. The fish swim indifferently in all directions; the drops fall into the vessel beneath; and, in throwing something to your friend, you need throw it no more strongly in one direction than another, the distances being equal; jumping with your feet together, you pass equal spaces in every direction. When you have observed all these things carefully (though there is no doubt that when the ship is standing still everything must happen in this way), have the ship proceed with any speed you like, so long as the motion is uniform and not fluctuating this way and that. You will discover not the least change in all the effects named, nor could you tell from any of them whether the ship was moving or standing still. In jumping, you will pass on the floor the same spaces as before, nor will you make larger jumps toward the stern than toward the prow even though the ship is moving quite rapidly, despite the fact that during the time that you are in the air the floor under you will be going in a direction opposite to your jump. In throwing something to your companion, you will need no more force to get it to him whether he is in the direction of the bow or the stern, with yourself situated opposite. The droplets will fall as before into the vessel beneath without dropping toward the stern, although while the drops are in the air the ship runs many spans. The fish in their water will swim toward the front of their bowl with no more effort than toward the back, and will go with equal ease to bait placed anywhere around the edges of the bowl. Finally the butterflies and flies will continue their flights indifferently toward every side, nor will it ever happen that they are concentrated toward the stern, as if tired out from keeping up with the course of the ship, from which they will have been separated during long intervals by keeping themselves in the air. . . .

SAGREDUS: Although it did not occur to me to put these observations to the test when I was voyaging, I am sure that they would take place in the way you describe. In confirmation of this I remember having often found myself in my cabin wondering whether the ship was moving or standing still; and sometimes at a whim I have supposed it going one way when its motion was the opposite. . . .

GALILEO'S PRINCIPLE OF RELATIVITY (1632)

[Things behave same way in an environment moving w/ const velocity, as in a stationary one. An experimental fact, but we can elevate it to a principle.]

LAWS OF PHYSICS ARE THE SAME IN ALL (INERTIAL) REFERENCE FRAMES.
(EQNS OF PHYSICS HAVE THE SAME FORM)

[Negative formulation is even more powerful]

NO EXPT CAN DISTINGUISH AMONG REFERENCE FRAMES.
NO EXPT CAN DETECT ABSOLUTE MOTION.

[Historical context: Galileo had a small dispute w/ authorities. He claimed earth in orbit around the sun. (30 km/s)
They argued that earth is at rest, because seems at rest.
He argued that whether at rest or in motion, things behave the same.]

[Given that principle of relativity is almost 400 yrs. old, why do we associate it with Einstein?]

In 19th century it was recognized that light consists of electromagnetic waves, governed by Maxwell eqns. Eqns predict that light wave travel at constant speed.]

LIGHT WAVES TRAVEL AT CONST SPEED c.

⇒ E+M APPARENTLY VIOLATES PRINCIPLE OF RELATIVITY

[If velocity is relative, how can light speed be same in all frames?
In particular, in frame moving with light wave, it would appear to be stationary.
But Maxwell's eqns do not allow stationary wave.
∴ they do not hold in that reference frame.
violating the principle of relativity.]

19th c'y PHYSICISTS POSTULATED LUMINIFEROUS ETHER,
A MEDIUM FOR LIGHT WAVES.
MAXWELL EQNS. ONLY HOLD IN REST FRAME OF ETHER.
[But expts failed to detect the ether]

EINSTEIN POSTULATED ∄ ETHER
AND MAXWELL EQNS HOLD IN ALL FRAMES.
[radical reformulation of space & time]