PHY312 - lecture 2

Simon Catterall

Review

- All physical phenomena observed from some frame of reference (x, y, z, t).
- Life is simple if this frame is inertial. (Observe uniform motion of object in absence of forces)
- Newtonian mechanics obeys a Relativity Principle – that is all such inertial FOR are equally good. Deduce same fundamental laws of Physics from any such frame.
- Newton assumed absolute time $t' = t$
- $F = ma$ takes same form in all such FOR.

Crisis

- Late 19th century new laws were discovered governing the phenomena of electricity and magnetism.
- In particular light seen as an electromagnetic wave with a fixed speed $c \simeq 3.0 \times 10^8$ m/s.
- But how can a law of physics contain a fundamental constant with the dimensions of velocity ?
- Seems to imply existence of a preferred FOR. Violates relativity principle ...
- Can show that EM equations do not have same form when $(x, y, z, t) \rightarrow (x', y', z', t')$ for two FOR with relative velocity v using Galilean transformations.

Resolution?

- OK, throw out relativity principle. Assume preferred reference frame – the ether. Velocity of light is measured relative to ether.
- But experients designed to measure speed of Earth relative to ether all returned null result!
- Michelson-Morley 1897. Ether dragging ?
- Einstein used this as cornerstone of a new theory - special relativity which aimed to preserve the relativity principle by throwing out the Newtonian way of relating distance and time between 2 inertial FOR.

Einstein's idea

- Relativity principle is central. Assume laws of electricity and magnetism correct.
- Forced to conclude that all inertial observers must agree on the numerical value of the speed of light!
- This is in conflict with the Newtonian way of computing relative velocity ...
- A light beam receeds at the same speed independent of how fast I run after it!
- Not like any other wave motion.

A thought experiment

- Consider rocket moving along x-axis of some (inertial) FOR at speed v.
- Imagine it sends out a light beam in y-direction which bounces off the rocket side and returns to the starting point.
- Emission and reabsorption are 2 events.
- If rocket has diameter h and light travels at speed c it will return in time $t_R = 2h/c$ according to rocket FOR.

More rockets

- How do they look from original FOR ? Simple geometry shows total distance gone is now $2\sqrt{h^2 + v^2 \frac{t}{2}^2}$ if t is time separation in original FOR.
- and If assume it moves at speed c still takes a time $t = 2\sqrt{h^2 + v^2 \frac{t}{2}^2}/c$ to return as measured by the original FOR.
- Algebra gives

$$t = t_R \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

- Not the same !! $t > t_R$.

Time is not absolute

- Time measured in “stationary” frame longer than “moving frame”. Time dilation.
- Notice also spatial separations

$$\Delta x_R = 0 \quad \Delta x = v\Delta t$$

.

- Observers who are in uniform relative motion ascribe different spatial and temporal differences to the same 2 physical events. Is there anything they agree on ?

Spacetime interval

- Easy to see that the quantity

$$\Delta s^2 = c^2 \Delta t^2 - \Delta x^2$$

  invariant (same for both sets of observers)
- Notice that for $c \to \infty$ just yields absolute time.
- Called the (square) of the spacetime interval (dimensions of length)
- Generalizes the notion of notion of distance in ordinary space. Thus familiar with the idea that the coordinates of the endpoints of ruler are not invariant under rotations or Galilean transformations. But length of ruler is ... This is the analog.

Things to do

- Suppose you open the door to a room (event 1) and walk at a constant speed of 1 m/s to a chair 10 m away and sit down (event 2).
- How much time elapses in the frame of the room between the two events. What is the spatial distance between the two events as seen from the room ?
- What is the distance in spacetime associated with these two events ?
- What is the spatial separation between the two events as measured in a frame which moves with you
- How much time is recorded on your watch ?
- How would things change if you could walk at 3/5 speed of light !

What follows

- Also allows us to define proper time between the two events $\tau = \Delta s/c$. Time interval measured by clock traveling with the rocket.
- For the proper time to be a *real* number **the velocity must be less than c!**. Maximum velocity ..
- Length of a worldline in spacetime is proportional to the proper time measured by a clock that travels along that path.
- What is shape of this spacetime path for a free particle ?
- What is the length of the path for a photon ?

Some philosophy

- Why should I believe such wierdness ?
  - It agrees extremely well with experiment.
  - It follows logically from the relativity principle which is really forced upon us by the impossibility of knowing how to establish a preferred FOR. Einstein “merely” extends Newton’s ideas to all physical laws not just mechanics
  - It reduces to Newtonian mechanics as $v/c \to 0$.
- While it violates intuitive feelings about how the world works there is no reason to trust these in regimes far from our commonsense experience. This is similar to quantum mechanics.

Conclusions

- Notice once more that in Special Relativity there is no absolute (observer independent) notion of space and time separately – only a funny fusion of the two – the thing we have been calling spacetime.

  Hendeforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a union of the two will preserve an independent reality

  Herman Minkowski (1864-1909)