K. Long, 23 November 2004

Relativity – Lecture 2

Foundations

Lecture 2: Foundations

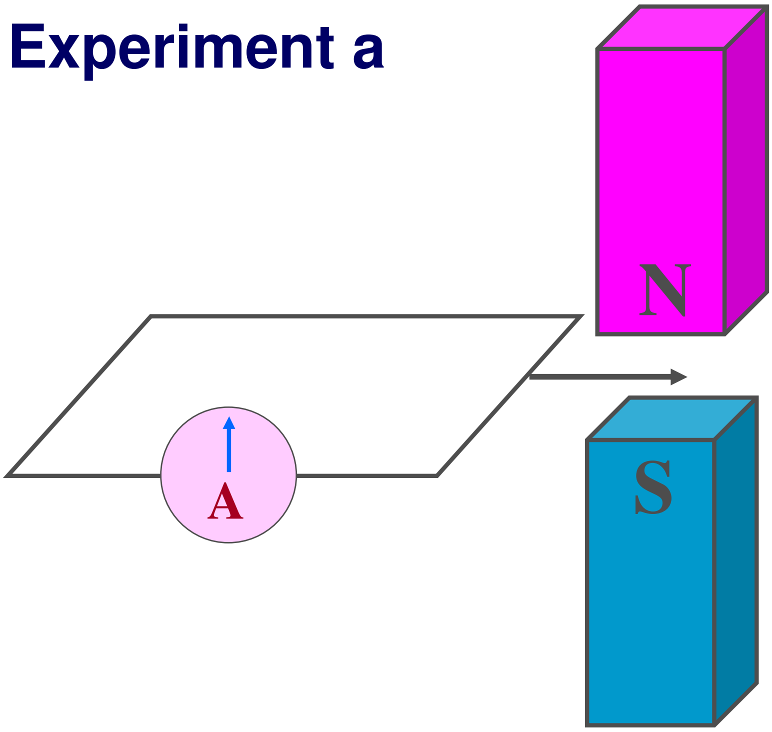
2.1 The principle of relativity

- The laws of physics are the same for all inertial observers
  - Einstein 1905
- Test case:
  - Electromagnetic induction:
    - Experiment a: Coil moves *over* stationary magnet
    - Experiment b: Magnet moves *over* stationary coil

    - Current pulse in exp^t a = current pulse in exp^t b

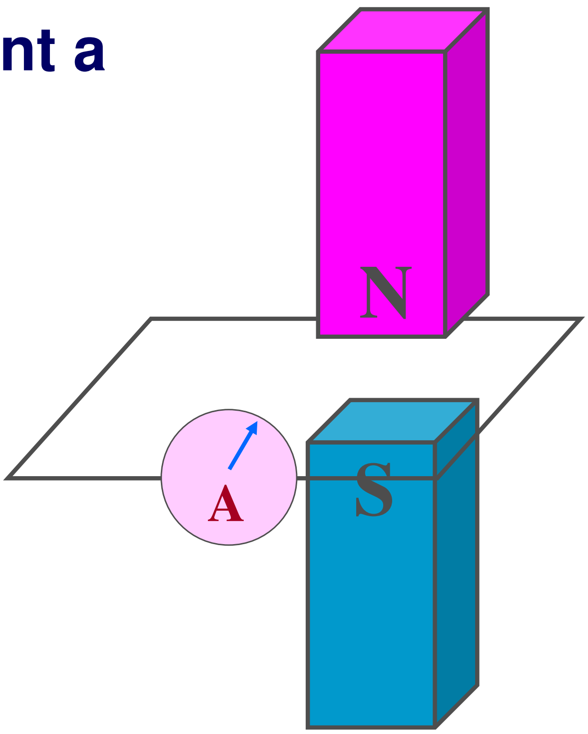
Electromagnetic induction

Experiment a



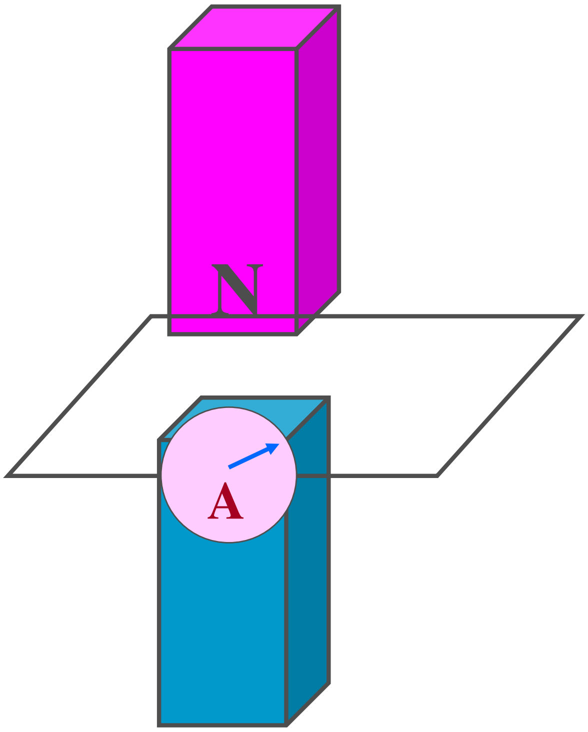
Electromagnetic induction

Experiment a



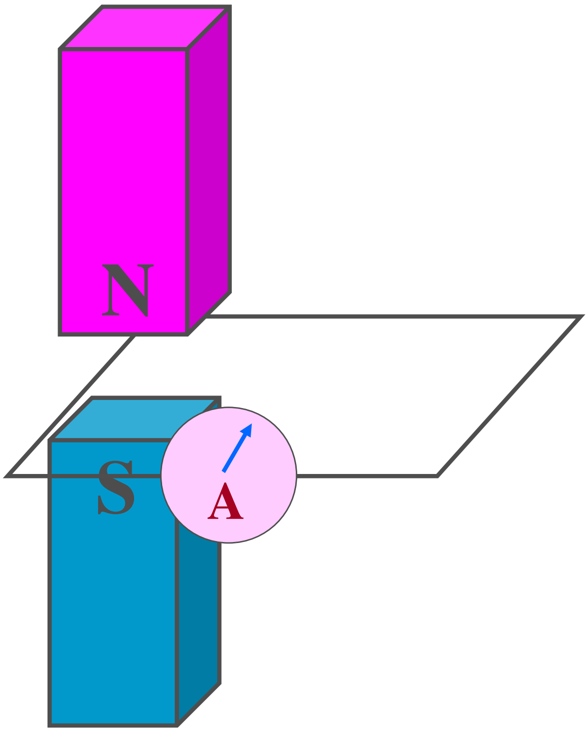
Electromagnetic induction

Experiment a



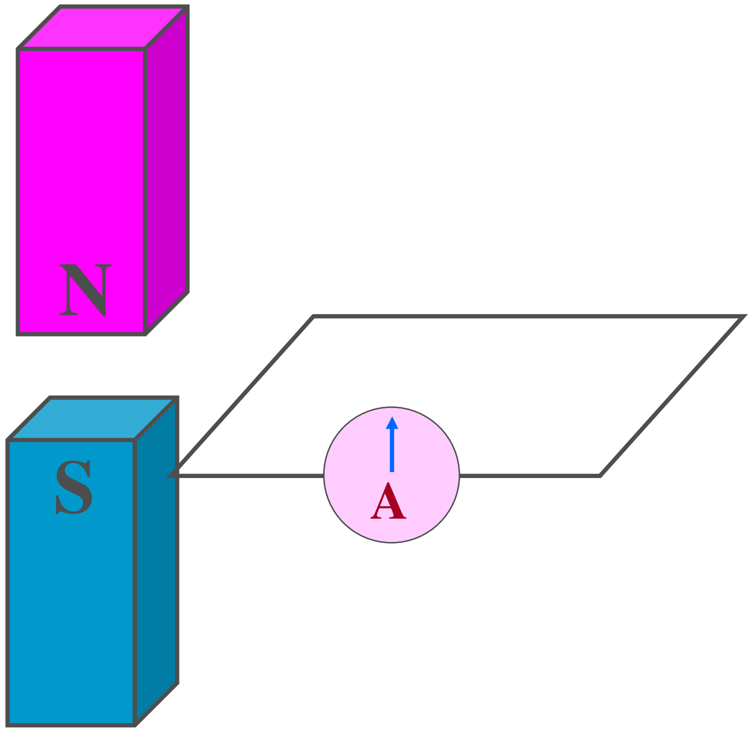
Electromagnetic induction

Experiment a

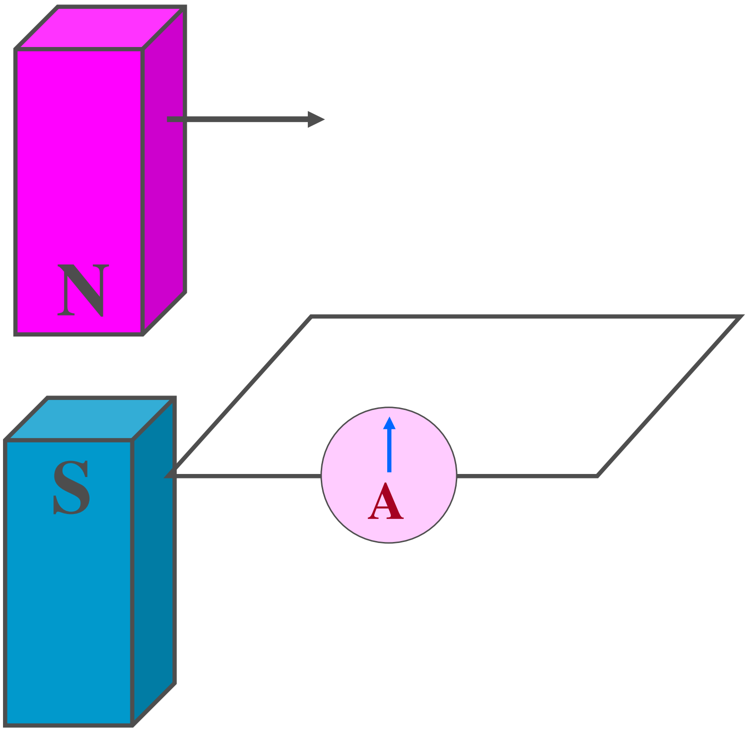


Electromagnetic induction

Experiment a

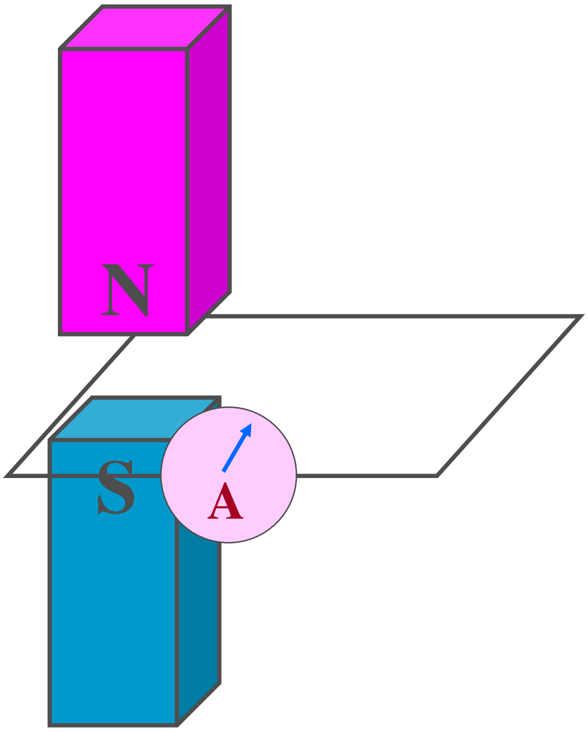


Electromagnetic induction



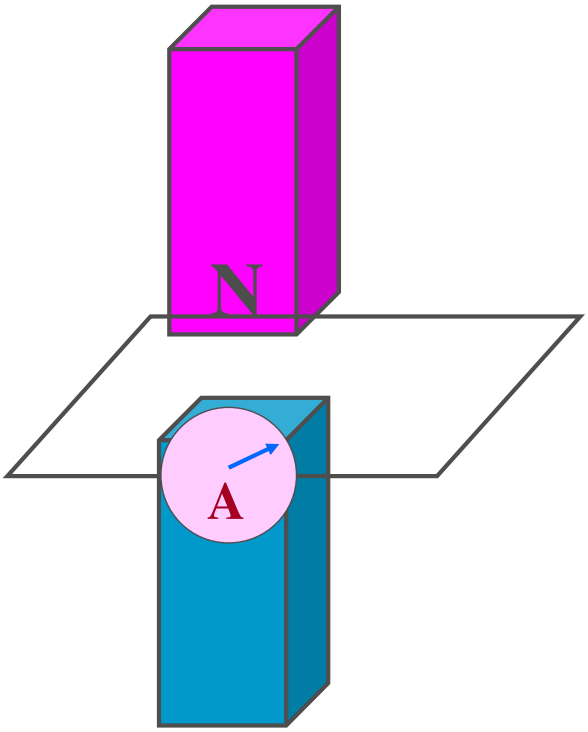
Experiment b

Electromagnetic induction



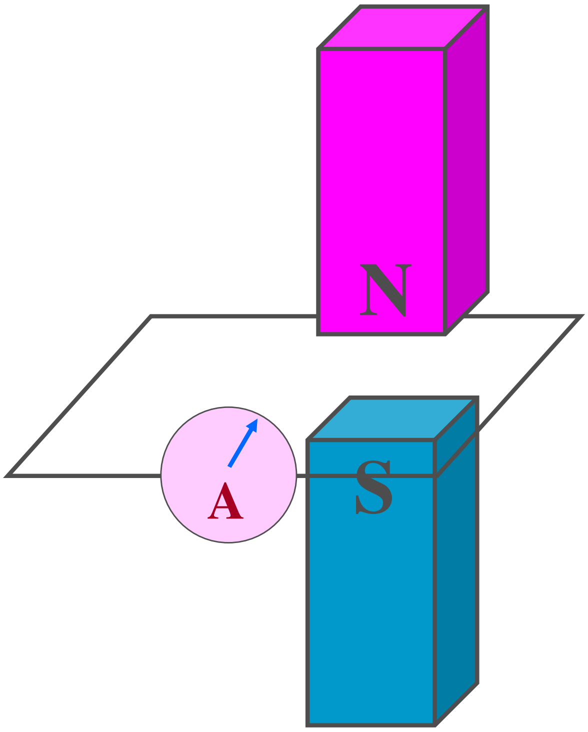
Experiment b

Electromagnetic induction



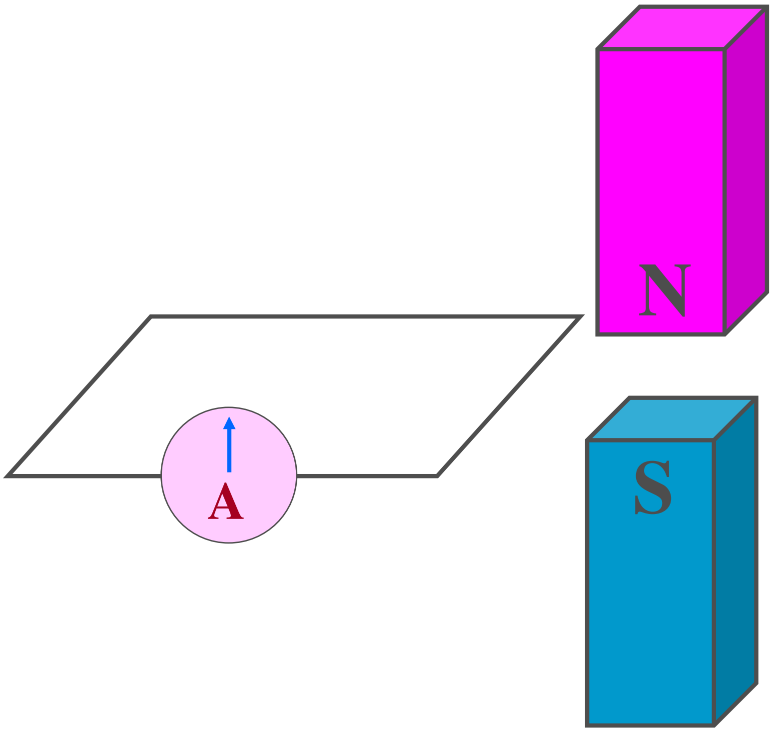
Experiment b

Electromagnetic induction



Experiment b

Electromagnetic induction



Experiment b

Lecture 2: Foundations

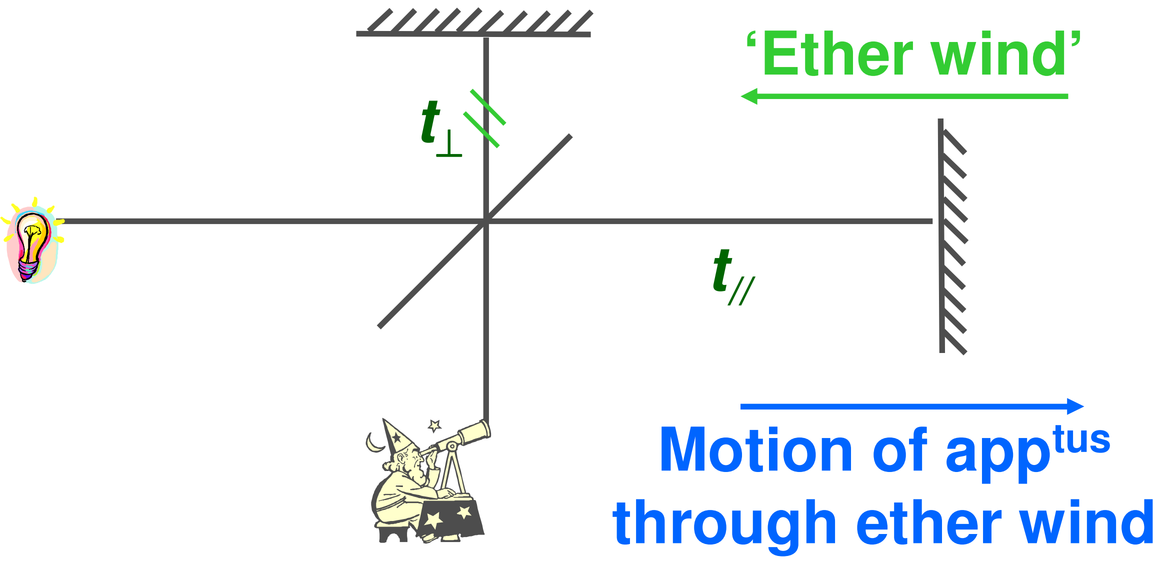
2.2 The speed of light

- Michelson-Moreley experiment
  - The speed of light is isotropic
    - See for example Alonso&Finn
- Kennedy-Thorndyke experiment:
  - The speed of light is the same for all inertial observers
    - See for example Taylor&Wheeler

Lecture 2: The speed of light

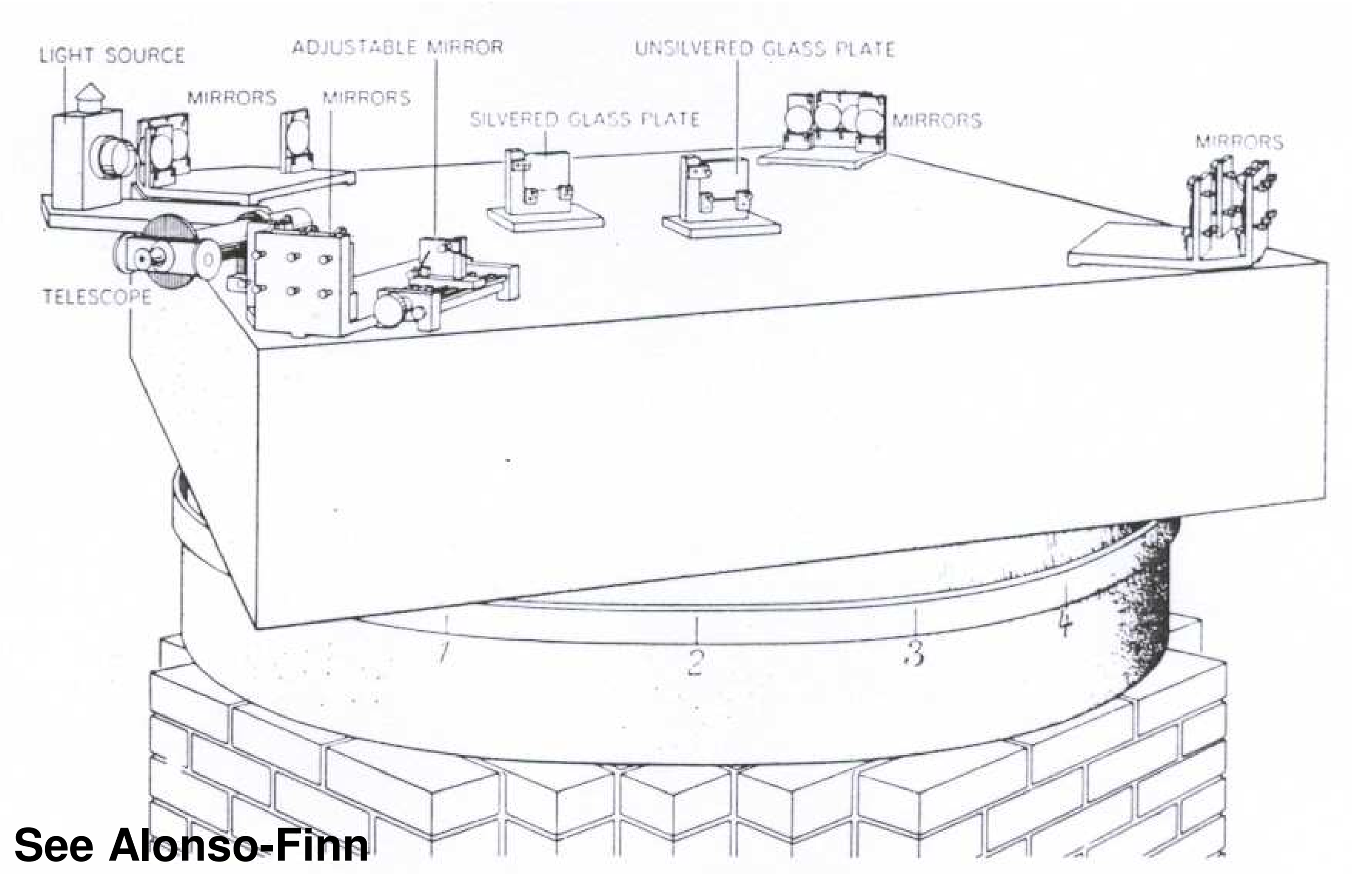
The speed of light is isotropic

- The Michelson-Moreley experiment:



- Galilean relativity predicts $t_{//} < t_\perp$
- In contradiction to observations

Lecture 2: The speed of light



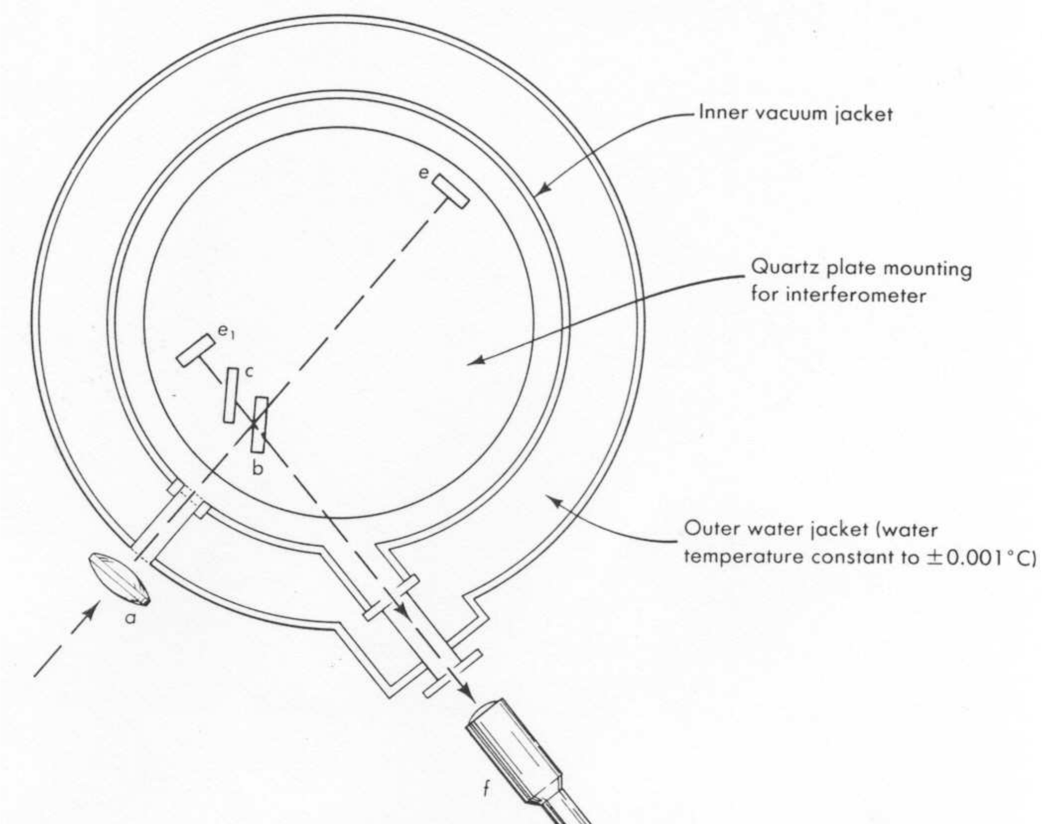
See Alonso-Finn

Lecture 2: The speed of light

The speed of light is the same for all inertial observers

- The Kennedy-Thorndyke experiment:
  - Set up interferometer
    - Summer: Earth's velocity relative to fixed stars *v*
    - Winter: Earth's velocity relative to fixed stars -*v*
  - No change in interference pattern observed
- Speed of light is the same for all inertial observers
- Speed of light is 'invariant'

Lecture 2: The speed of light



See Taylor and Wheeler

Lecture 2: Foundations

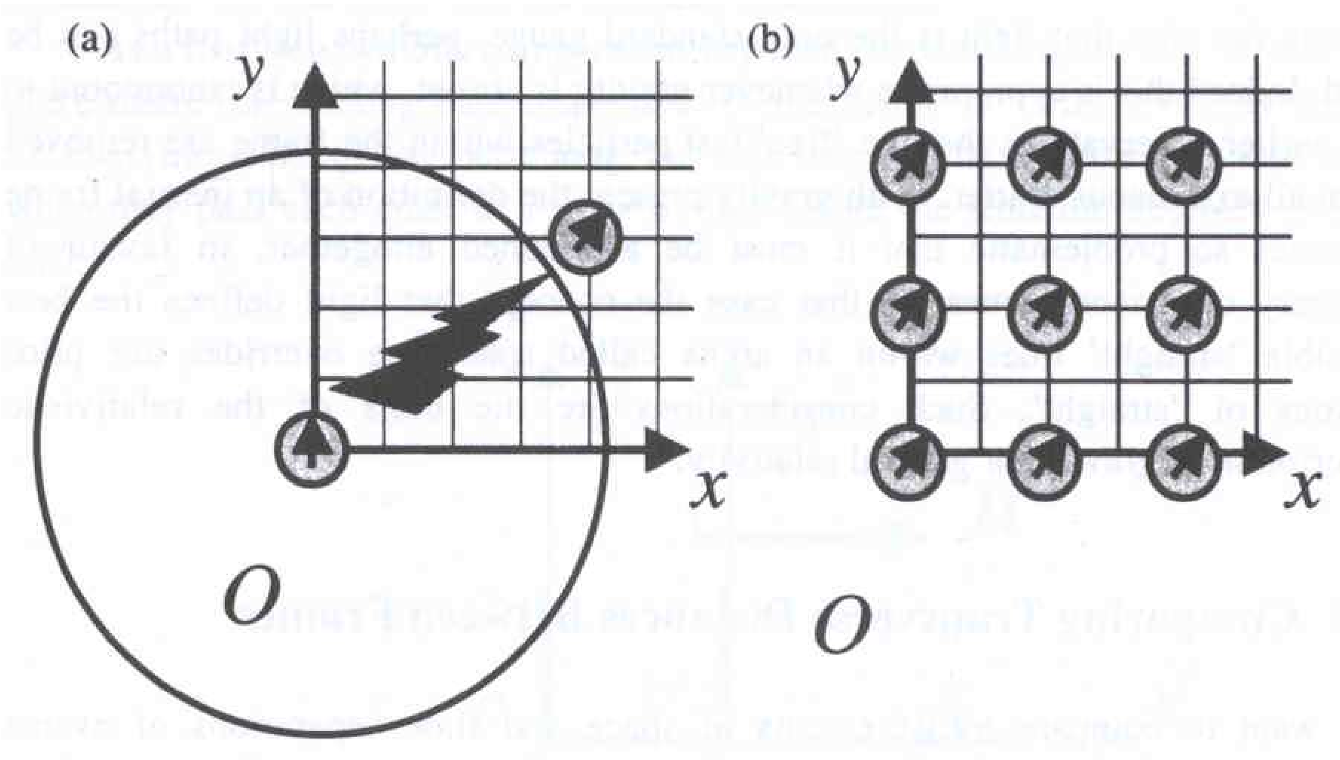
2.3 The principle of relativity (reworded)

- **Invariant quantities:**
  - **Same *NUMERICAL VALUE* in all inertial frames**
- **Covariant expressions:**
  - **Take same *FORM* in all inertial frames**

- **The laws of Physics are *COVARIANT***
- **The speed of light is *INVARIANT***

Lecture 2: Foundations

2.4 Practical definition of coordinate system

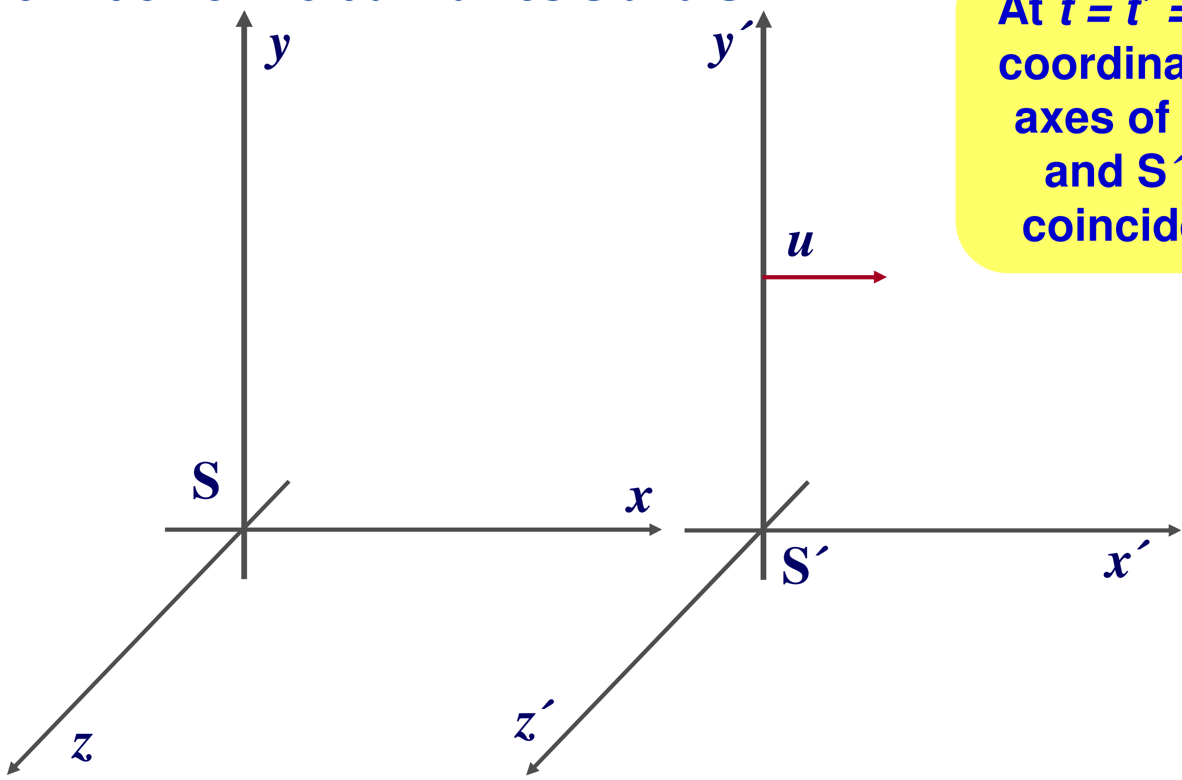


Lecture 2: Foundations

Inertial frames

[reminder!]

- **Definition of inertial frames *S* and *S´*:**

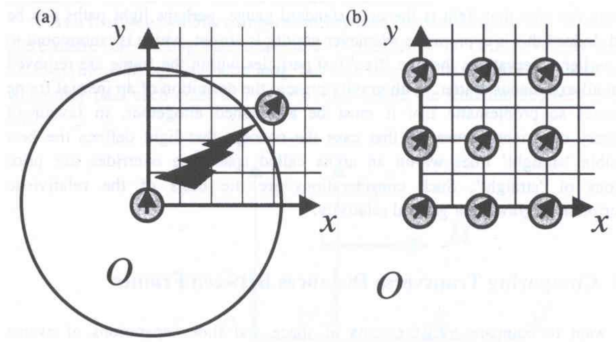


At $t = t´ = 0$ coordinate axes of S and S´ coincide

Lecture 2: Foundations

Synchronisation of clocks

- Lattice work of rods and clocks (see McCall)
- Synchronisation:
  - Set each clock s.t.: $t_0 = \frac{r}{c}$
  - Send spherical light pulse from $x=y=z=0$ at $t=0$
  - Start each clock as light wave reaches it



- Since coordinate axes of S and S' coincide at $t=t'=0$, correct relative setting of clocks guaranteed

Lecture 2: Foundations

2.5 The light clock

- Cycle: mirror 1 $\rightarrow$ mirror 2 $\rightarrow$ mirror 1
  Analogous to full swing of pendulum of grandfather clock

2.6 Distances transverse to relative velocity

- Rod (length 1m) set up along y axis in S
- Rod (length 1m) set up along y' axis in S'
- O observes length of rod in S' to be l
- O' observes length of rod in S to be l'
- Principle of relativity $\Rightarrow$ $l = l'$
- Contradiction unless $l = l' = 1$m

Lecture 2: Foundations

- Lorentz transformation (part 1):

Transformation	Inverse transformation
$y' = y$	$y = y'$
$z' = z$	$z = z'$

2.7 Time dilation (revisited)

- Time interval between two events which take place at same point in space in $S' = T'$
- Time interval between the same two events but observed from $S = T$
- NB the two events do not occur at the same point when observed from S

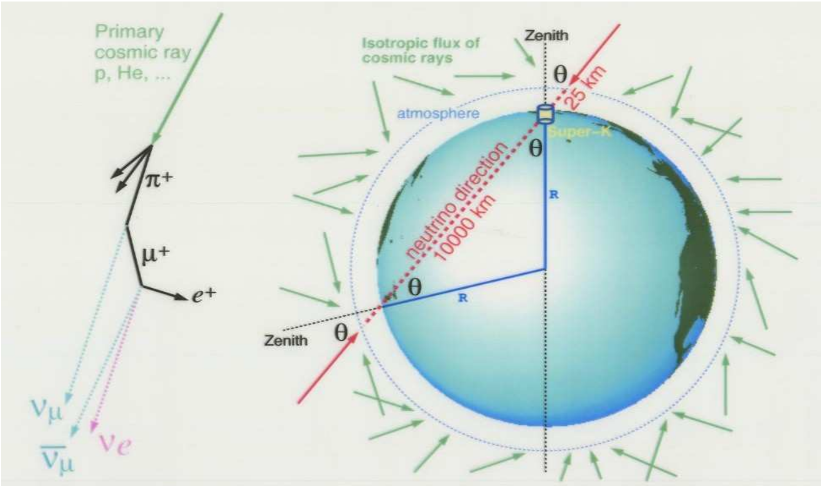
Lecture 2: Foundations

- Definitions: $\gamma = \dfrac{1}{\sqrt{1-\beta^2}} \qquad \beta = \dfrac{u}{c}$

- Time dilation: $T = \gamma T'$

Lecture 2: Foundations

2.8 Solution to problem of cosmic ray muon (revisited)



- **Define: muon to be at rest in frame *S′***
  - **Two events: Muon created: $t' = 0$**
    Muon decays: $t' = T'$
  - **Time difference measured in $S' = T'$**

Lecture 2: Foundations

- **Define earth frame: *S***
- **Relative velocity of *S′* and *S*: $u = 0.99984c$**
- **Two events viewed from earth frame *S*:**
  - **Production: height = h_0 at time $t = t_0$**
  - **Decay: height = h_1 at time $t = t_1$**
- **Two events do not occur at same point:**

  i.e. $h_0 > h_1$

Lecture 2: Foundations

- Calculate time between production and decay as seen from earth:
  - Step 1: $$\beta = \frac{u}{c} = 0.99984 \quad \Rightarrow \quad \gamma = \frac{1}{\sqrt{1-\beta^2}} = 56.6$$
  - Step 2: $$T = \gamma T' = 56.6T'$$
  - Step 3: Muon lifetime at rest = 2.2 μs
    Apparent muon lifetime = 125 μs
    (viewed from earth)
  - Step 4: Distance production to decay ~ 15km
    Implies time of flight ~50 μs
    Survival probability: $$e^{-\frac{50}{125}} \approx 70\%$$