Relativity — Lecture 1

- Outline, books, admin
- What is Relativity
- Galilean Relativity
- Moving magnets and coils
- Luminiferous Æther
- Michelson Morley Experiment

13/11/2007

Imperial College London
100 years of living science

Patrick Koppenburg

Highlights

- The laws of physics are identical in all inertial frames
- The speed of light in vacuum is a constant
- Moving bodies appear shorter
- Moving clocks appear to run slow
- $E_0 = mc^2$
- $ct^2 - x^2 - y^2 - z^2$ is invariant

Course Outline

1. **Introduction**
   Galilean relativity. Electromagnetism and optics. Michelson-Morley experiment. Postulates of special relativity.
2. **Consequences of the Invariance of speed of light**
   Simultaneous events. Light clocks. Relativity of time. Relativity of length.
3. **Lorentz Transformations**
   Invariance and covariance. Lorentz contraction. Time dilation. Measurement of velocity. Doppler effect.
4. **Relativistic Mechanics**
   Energy. Energy and momentum conservation. Some useful relations.
5. **Applications**
   Units. Nuclear physics. Particle collisions.
6. **Four-Vectors**
   Space-time geometry. Scalar product. Four-momentum.

Lecture Notes and Books

I have prepared lecture notes which cover everything.

They will be handed out fortnightly and also put on `webCT`.

The slides will be on `webCT` as well.

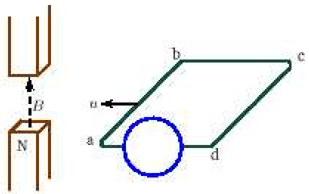


Figure 1: A moving coil and a magnet at rest.

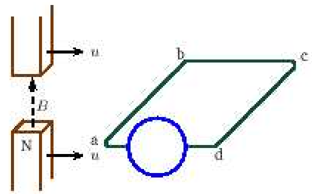


Figure 2: A moving magnet and a coil at rest.

When the magnet reaches segment ab the variation of the magnetic flux through the surface S defined by the coil causes a variation of the electric field E along the path C around the coil. This results in a current measured by the amperemeter A. Then while the magnet is inside the coil the flux does not vary and there is no current, finally when the magnet crosses cd the flux decreases which induces a current of the opposite sign.

In both cases the measured current pulses are the same (Fig. 3) but the interpretation is different. This experiment does not allow to tell which of the coil or the magnet is at rest, if any.

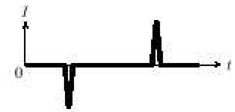


Figure 3: Current shown by the amperemeter.

1.4.2 Measurement of the Speed of Light

The next experiment deals with the speed of light, which plays a central role in special relativity. One of the biggest debates in the history of physics was about the nature of light. Is it corpuscular or a wave? We now know it's both, but at the end of the XIXth century the problem seemed to have been settled in favour of the wave nature by Huygens and Maxwell.[2] Let's see what predictions we get from these two hypotheses.

If light is corpuscular (emitted like bullets) one expects the speed of light to depend on the speed of the source. Can one infer the speed of the source by measuring the speed of light?

For instance the light emitted in front of a plane travelling at speed u (Fig. 4) would be travelling at speed $c+u$ and the light emitted from the rear at speed $c-u$.

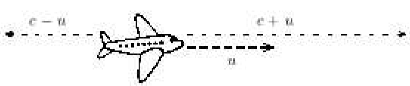


Figure 4: Corpuscular light hypothesis.

If this was the case one could have systems of binary stars in which one star could be seen at two places at the same time. See Problem 1.1.

[2] Einstein's article on the photoelectric effect [7] published the same year as the one proposing special relativity would give a strong argument for the corpuscular nature though.

Lecture Notes and Books

Hugh D. Young and Roger A. Freedman — *University Physics*

The standard all-in-one textbook. Contains all you need to know except four-vectors. Lacks some enthusiasm.

A.P. French — *Special Relativity*

A good and very clear book at the appropriate level. Some examples are a little out of date.

John B. Kogut — *Introduction to Relativity*

A more modern book, but much shorter. Some difficult topics lack explanation. Many explanations are based on Minkovski diagrams, which take some time to be understood.

Taylor and Wheeler — *Spacetime Physics*

A massive book with a different — very informal — approach. Taylor and Wheeler start from what's invariant and slowly get to the maths. Very detailed and explanation of paradoxes and brainteasers. This is the only place I found a clear and complete explanation of the twin paradox.

Richard Feynman et al. — *Feynman Lectures on Physics*

Feynman's excellent series includes three chapters on relativity. Feynman is always an illuminating background reading. But as usual Feynman only focuses on what's interesting to him.

Time Table

10 Lectures on Tuesdays and Thursdays at 14h.

- Except this Thursday, at 16h.

3 Classworks Thursdays at 15h.

- 22/11 (L4)
- 6/12 (L8)
- 13/12 (L10)

2 Problem sheets

1 APS on 23/11.

Test on 7/01.

Admin

Contact Details:

e-mail: `p.koppenburg@imperial.ac.uk`

This is the best way to contact me.

Office Hours: Tuesday 16h-17h at Blackett 525.

Course Associates:

Dr. John Hassard

`j.hassard@imperial.ac.uk`

Blackett 504

Dr. Ulrik Egede

`u.egede@imperial.ac.uk`

Blackett 523

Announcements

The Blackett Centenary Lecture

The Big Questions in Particle Physics and Cosmology

John Ellis FRS

TODAY 17:30
The Great Hall, Sherfield Building

See Details.

Announcements

Annual Schrödinger Lecture

Discovering the Quantum Universe: The Large Hadron Collider Project at CERN

Professor Jim Virdee

Wednesday 21 November 17:30
The Great Hall, Sherfield Building

See Details. Registration required!

Lecture 1

What is Relativity?

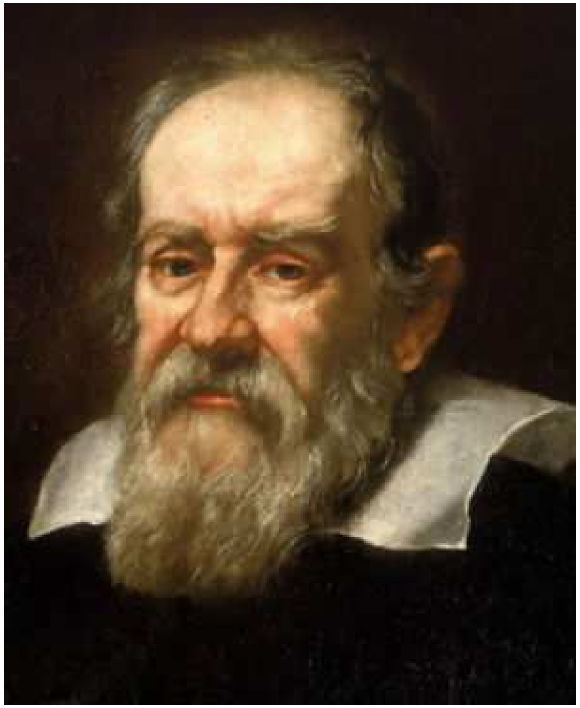
Definition — Relativity:
Relativity is a theory describing the relation between observations (measurements) of the *same* process by *different* observers in motion *relative* to each other.

Special Relativity refers to the special case of *inertial* observers.

General Relativity refers to the general case of *accelerated* observers and provides a theory of gravity.

Galilean Relativity

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 doubtless 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. And if smoke is made by burning some incense, it will be seen going up in the form of a little cloud, remaining still and moving no more toward one side than the other. The cause of all these correspondences of effects is the fact that the ship's motion is common to all the things contained in it, and to the air also. That is why I said you should be below decks; for if this took place above in the open air, which would not follow the course of the ship, more or less noticeable differences would be seen in some of the effects noted.



Galileo Galilei (1564–1642)

[Dialogue Concerning the Two Chief World Systems, 1632]

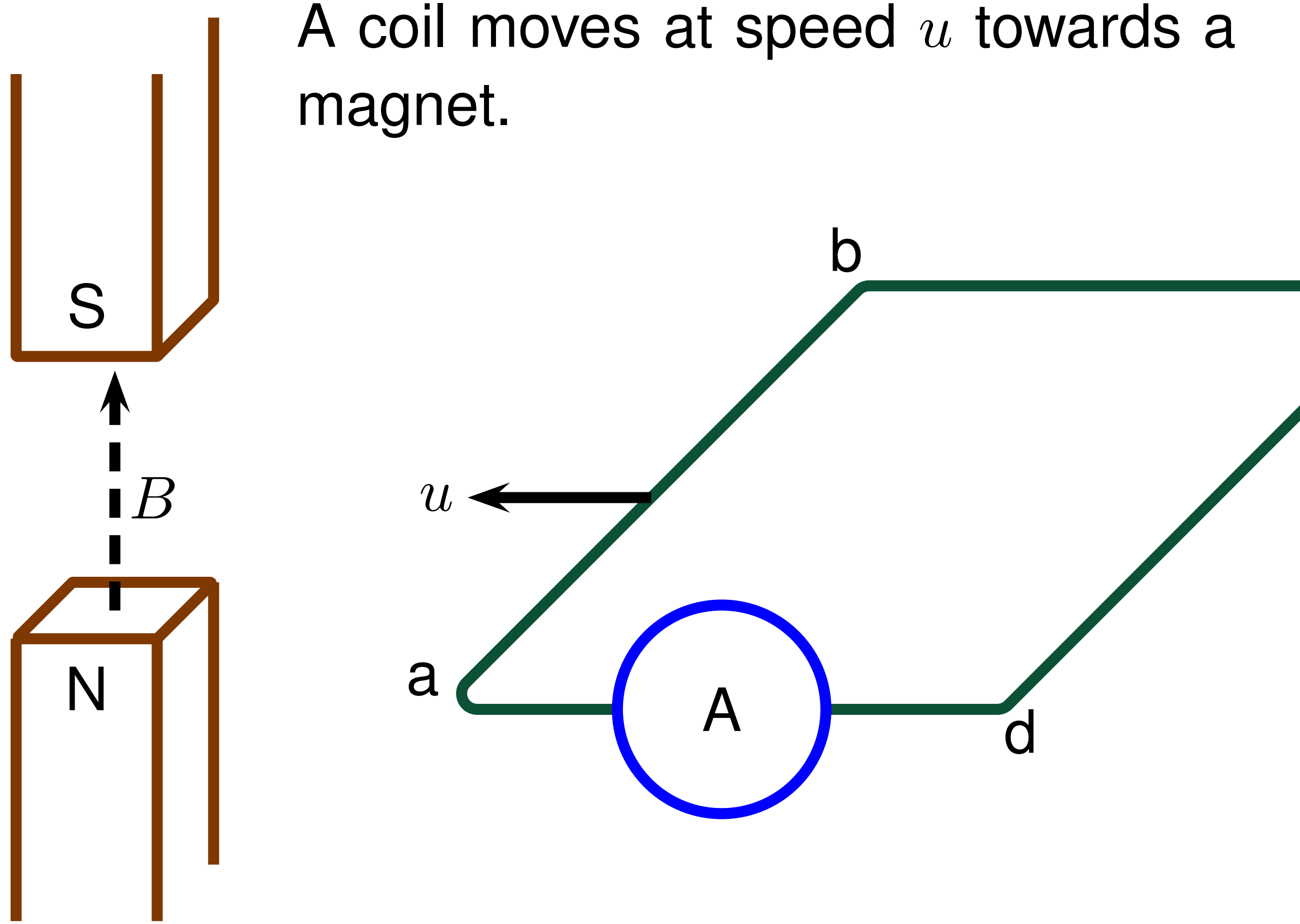
Galilean Relativity

Definition — Inertial frame:
A reference frame in which the first Newton law holds. An isolated body maintains a uniform velocity relative to any inertial frame.

Galileo's relativity :
The laws of Mechanics are the same in all inertial frames.

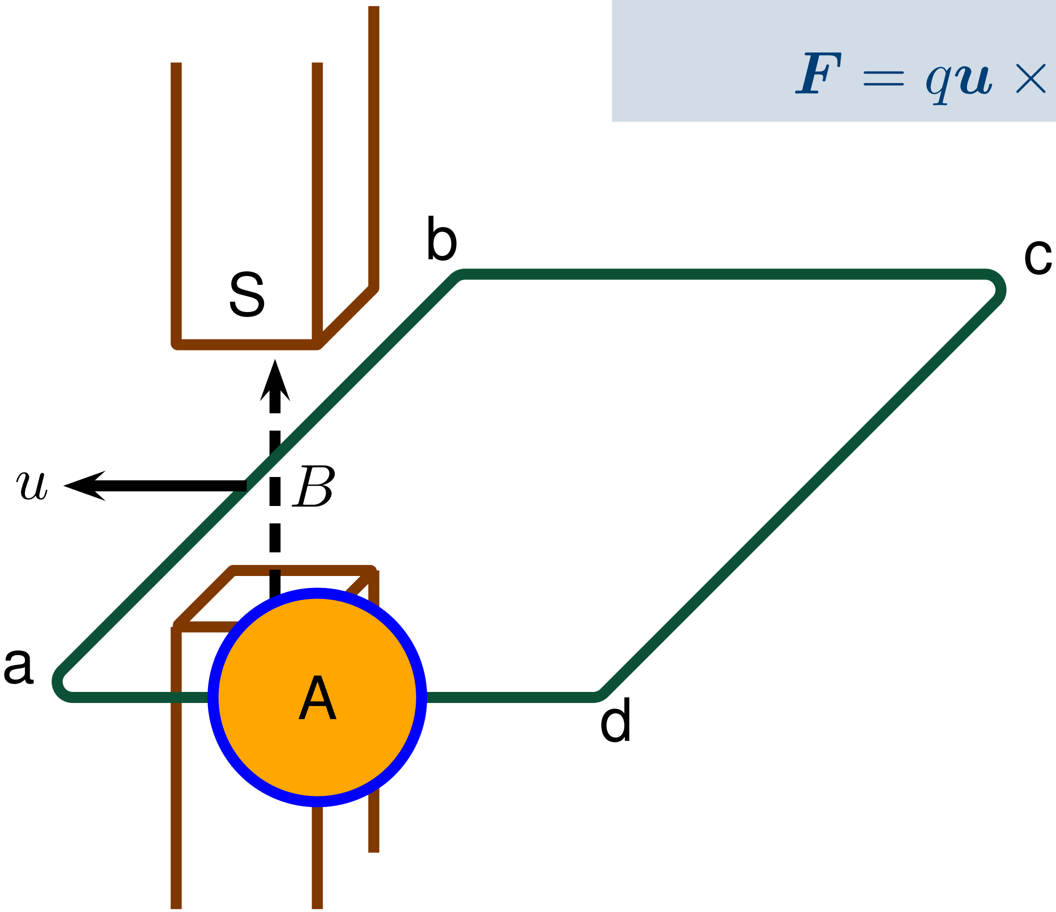
A Moving Coil

A coil moves at speed u towards a magnet.



A Moving Coil

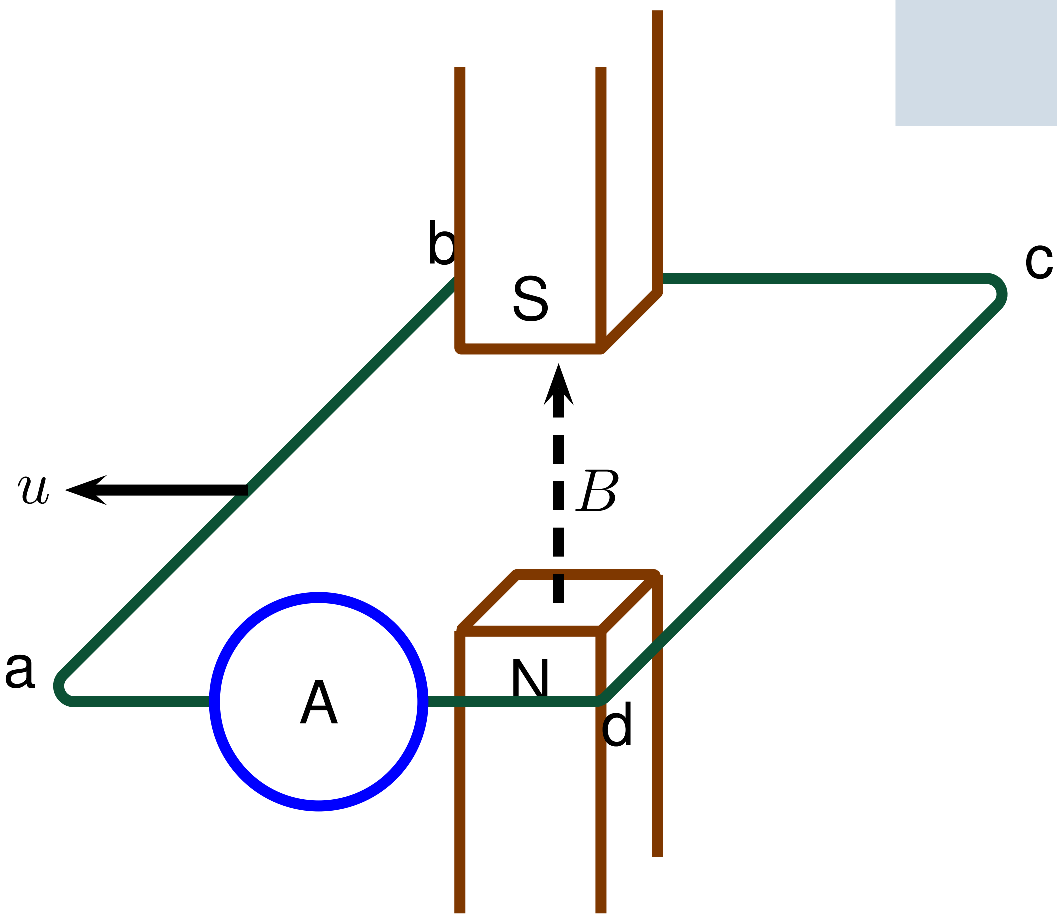
$$\boldsymbol{F} = q\boldsymbol{u} \times \boldsymbol{B}$$



Charges in ab in B field $\rightarrow F \rightarrow$ Current

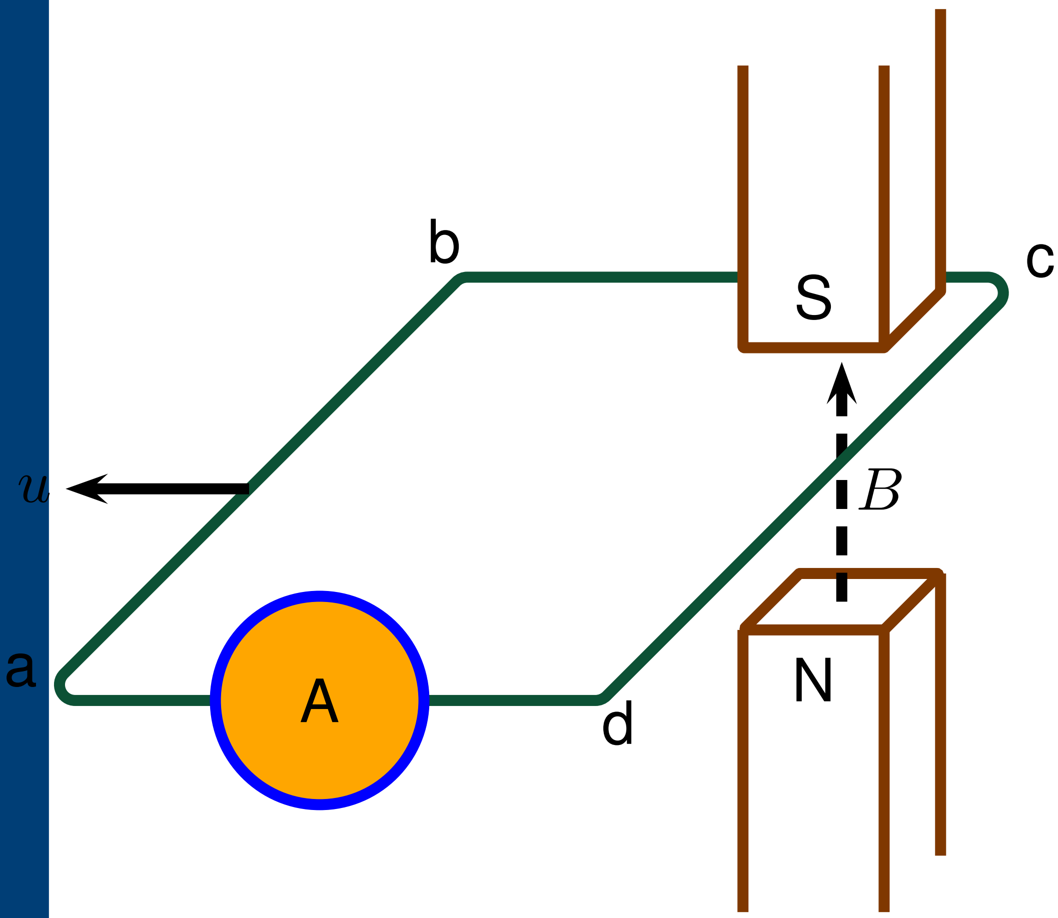
A Moving Coil

$$\boldsymbol{F} = q\boldsymbol{u} \times \boldsymbol{B}$$



No charges in B field $\rightarrow$ No current

A Moving Coil

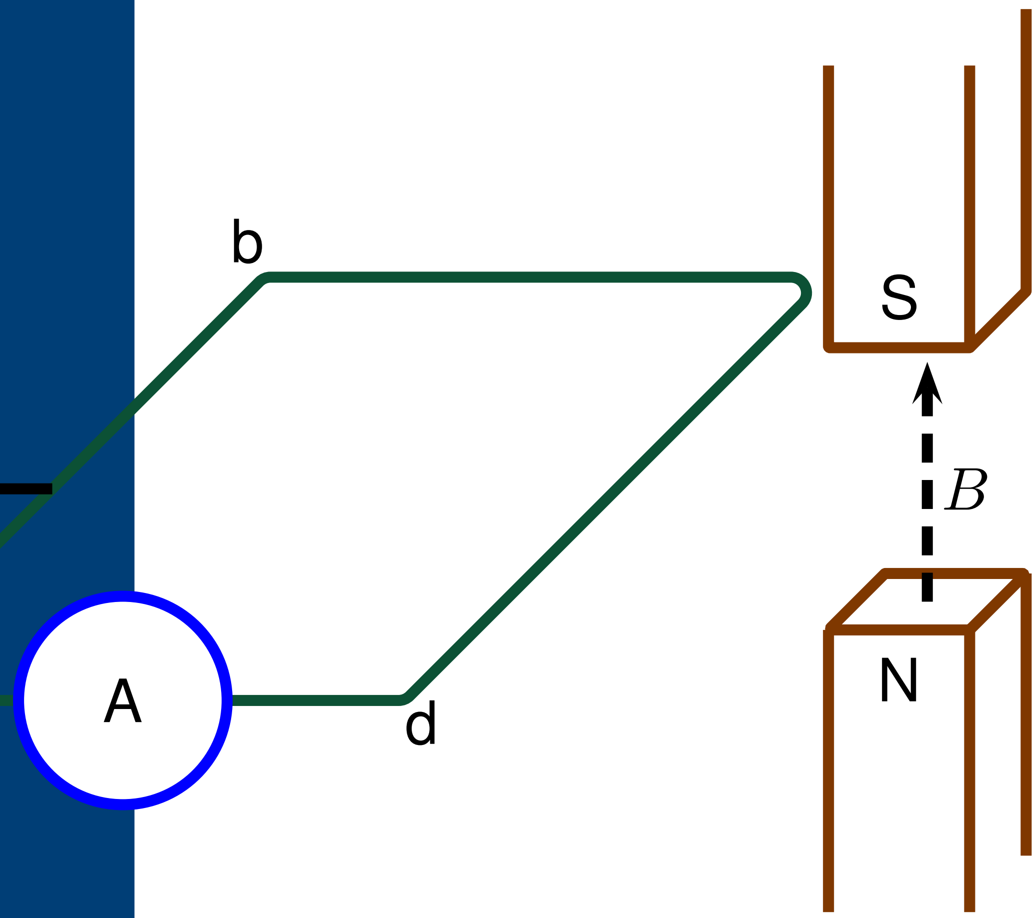


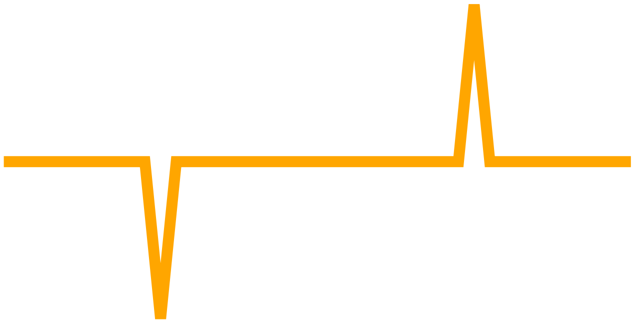
$$\boldsymbol{F} = q\boldsymbol{u} \times \boldsymbol{B}$$

Charges in cd in B field $\rightarrow F \rightarrow$ Current

A Moving Coil

$$\boldsymbol{F} = q\boldsymbol{u} \times \boldsymbol{B}$$

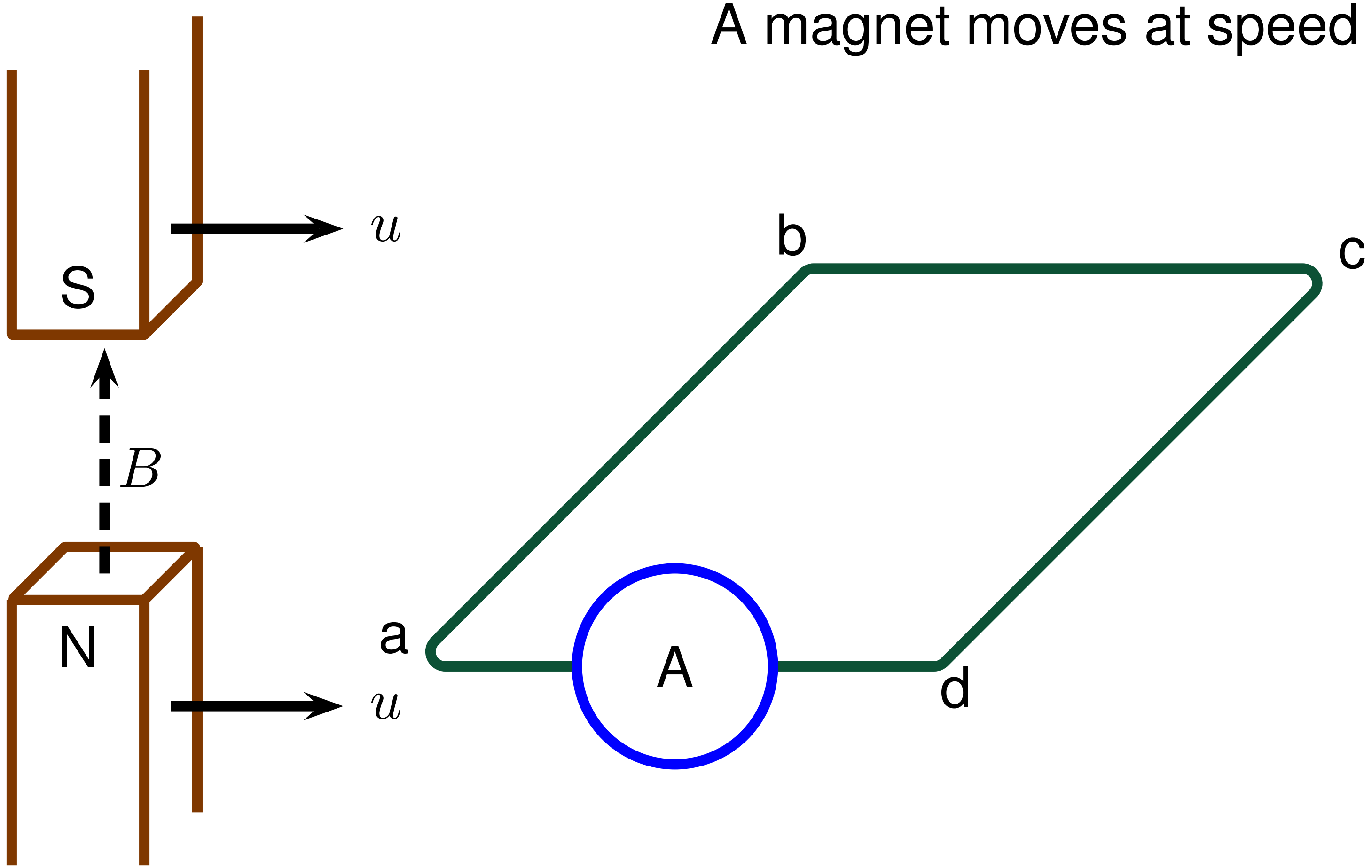




Charges out of B field $\rightarrow$ No current

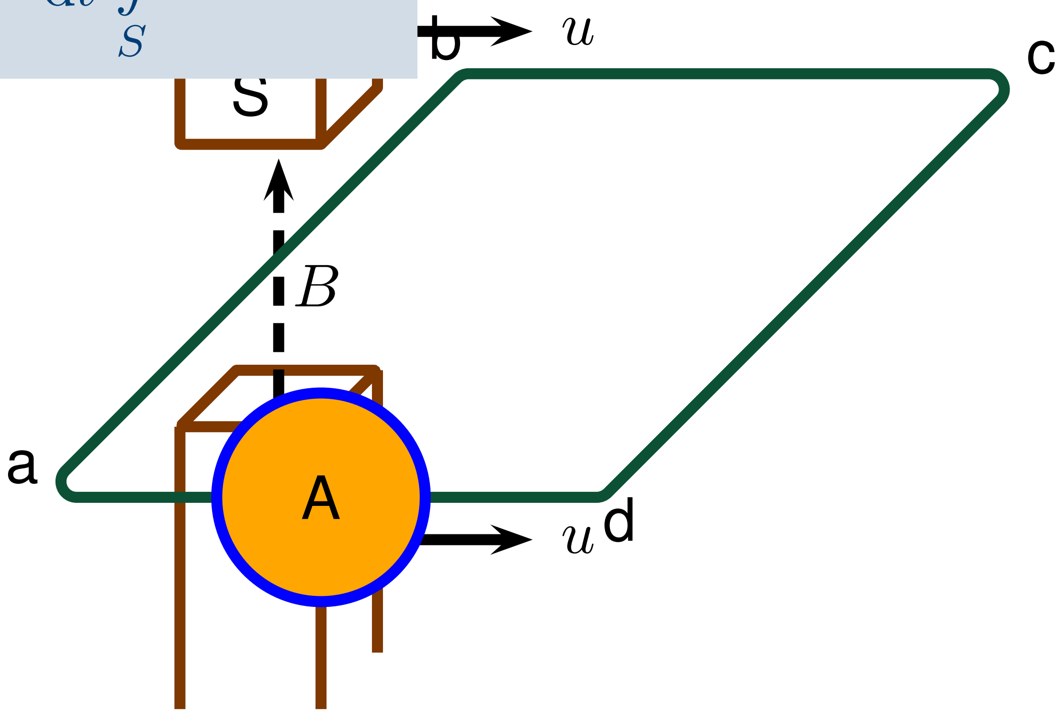
A Moving Magnet

A magnet moves at speed u towards a coil.



A Moving Magnet

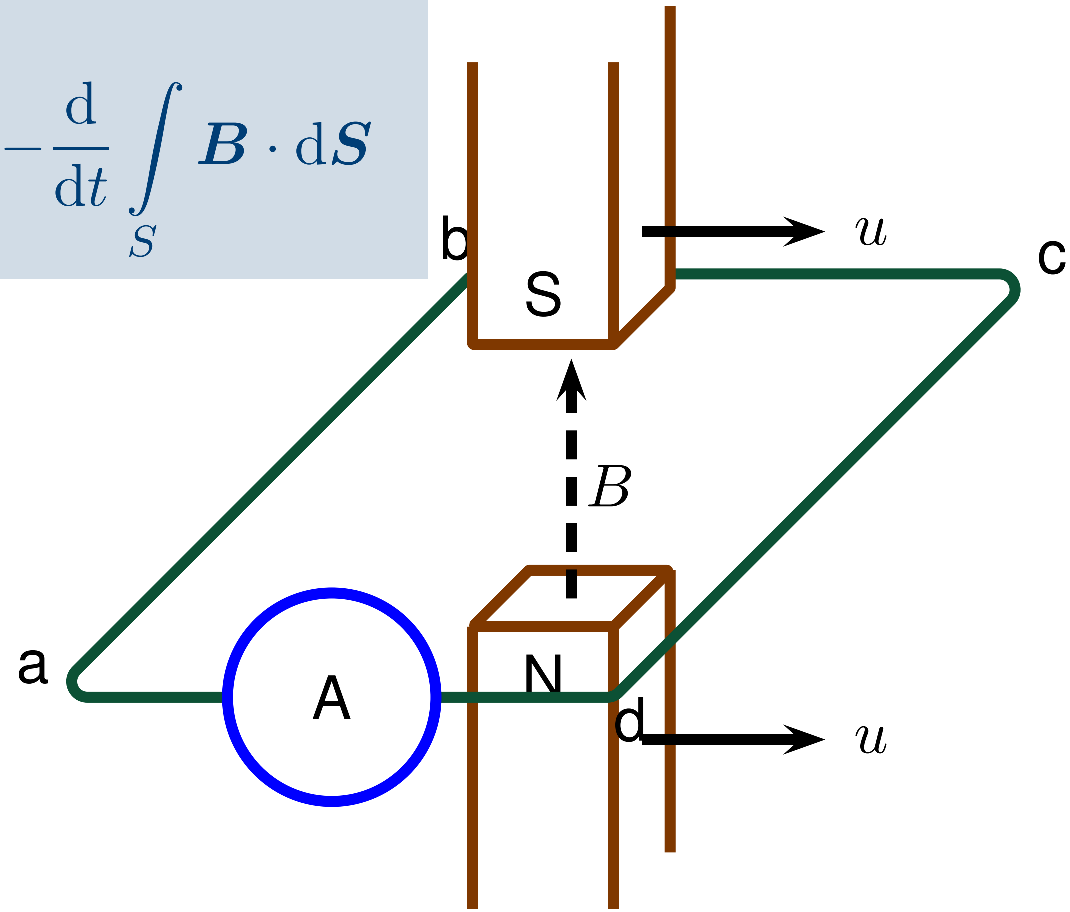
$$\int_C \boldsymbol{E} \cdot \mathrm{d}\boldsymbol{l} = -\frac{\mathrm{d}}{\mathrm{d}t} \int_S \boldsymbol{B} \cdot \mathrm{d}\boldsymbol{S}$$



Increase of B flux $\rightarrow E \rightarrow$ Current

A Moving Magnet

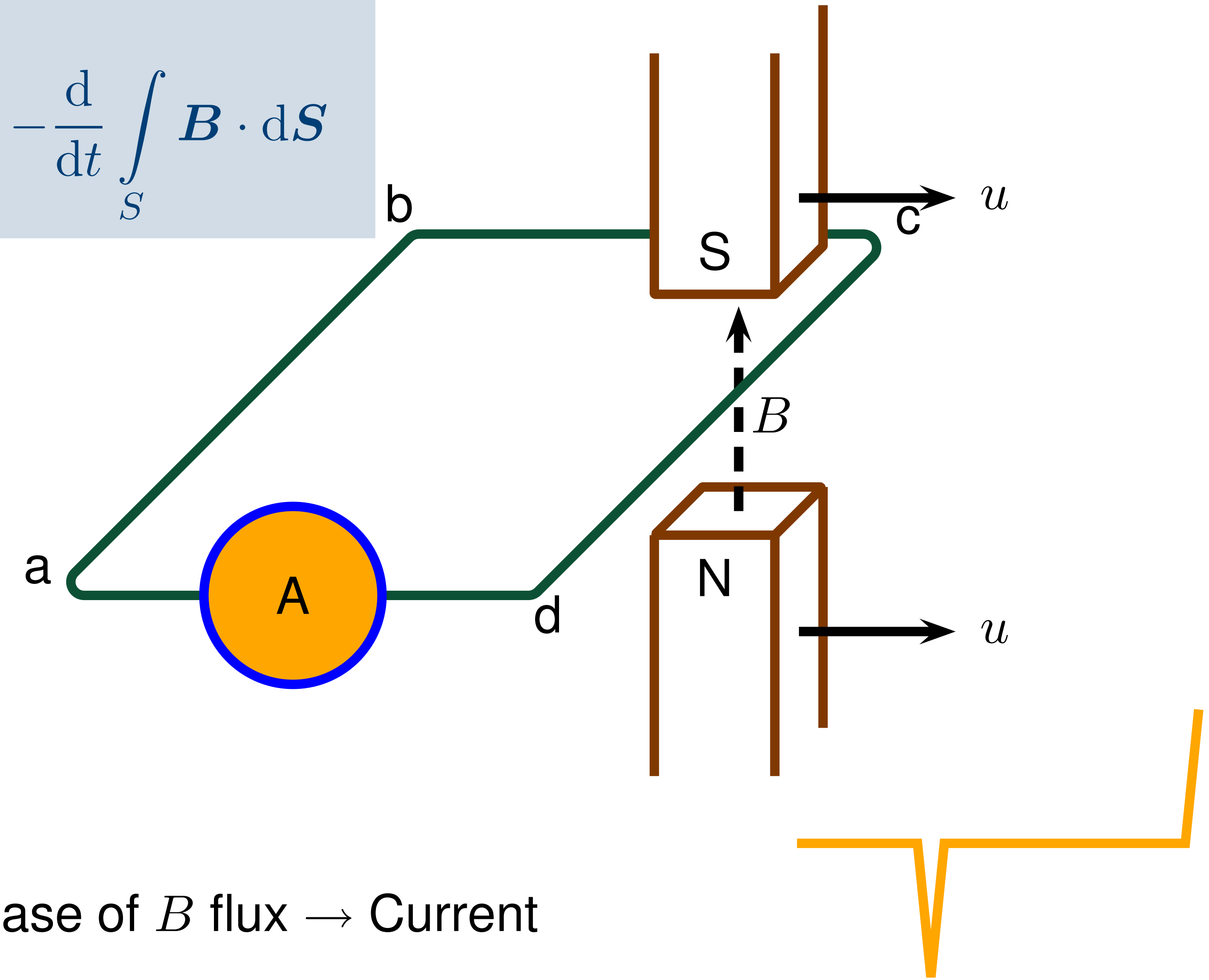
$$\int_C \boldsymbol{E} \cdot \mathrm{d}\boldsymbol{l} = -\frac{\mathrm{d}}{\mathrm{d}t} \int_S \boldsymbol{B} \cdot \mathrm{d}\boldsymbol{S}$$



Constant B flux $\rightarrow$ no current

A Moving Magnet

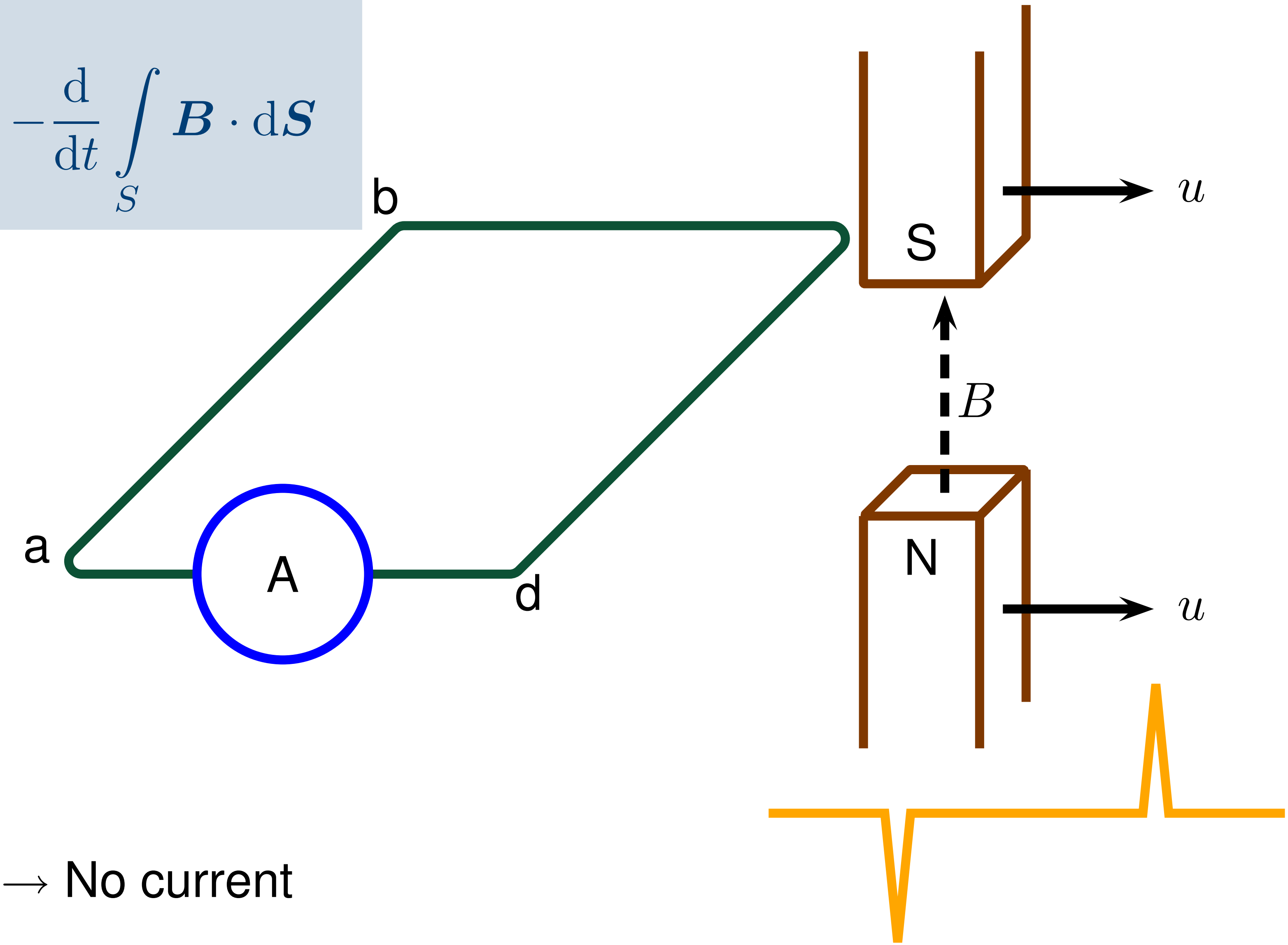
$$\int_C \boldsymbol{E} \cdot \mathrm{d}\boldsymbol{l} = -\frac{\mathrm{d}}{\mathrm{d}t} \int_S \boldsymbol{B} \cdot \mathrm{d}\boldsymbol{S}$$



Decrease of B flux $\rightarrow$ Current

A Moving Magnet

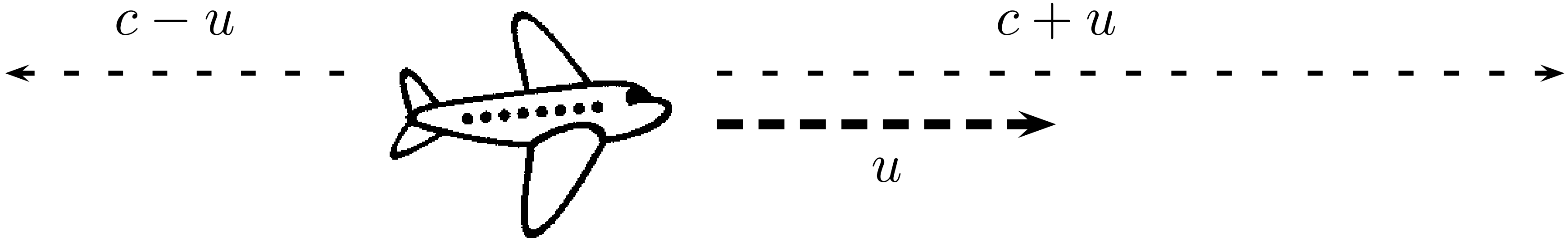
$$\int_C \boldsymbol{E} \cdot \mathrm{d}\boldsymbol{l} = -\frac{\mathrm{d}}{\mathrm{d}t} \int_S \boldsymbol{B} \cdot \mathrm{d}\boldsymbol{S}$$



No $B \rightarrow$ No current

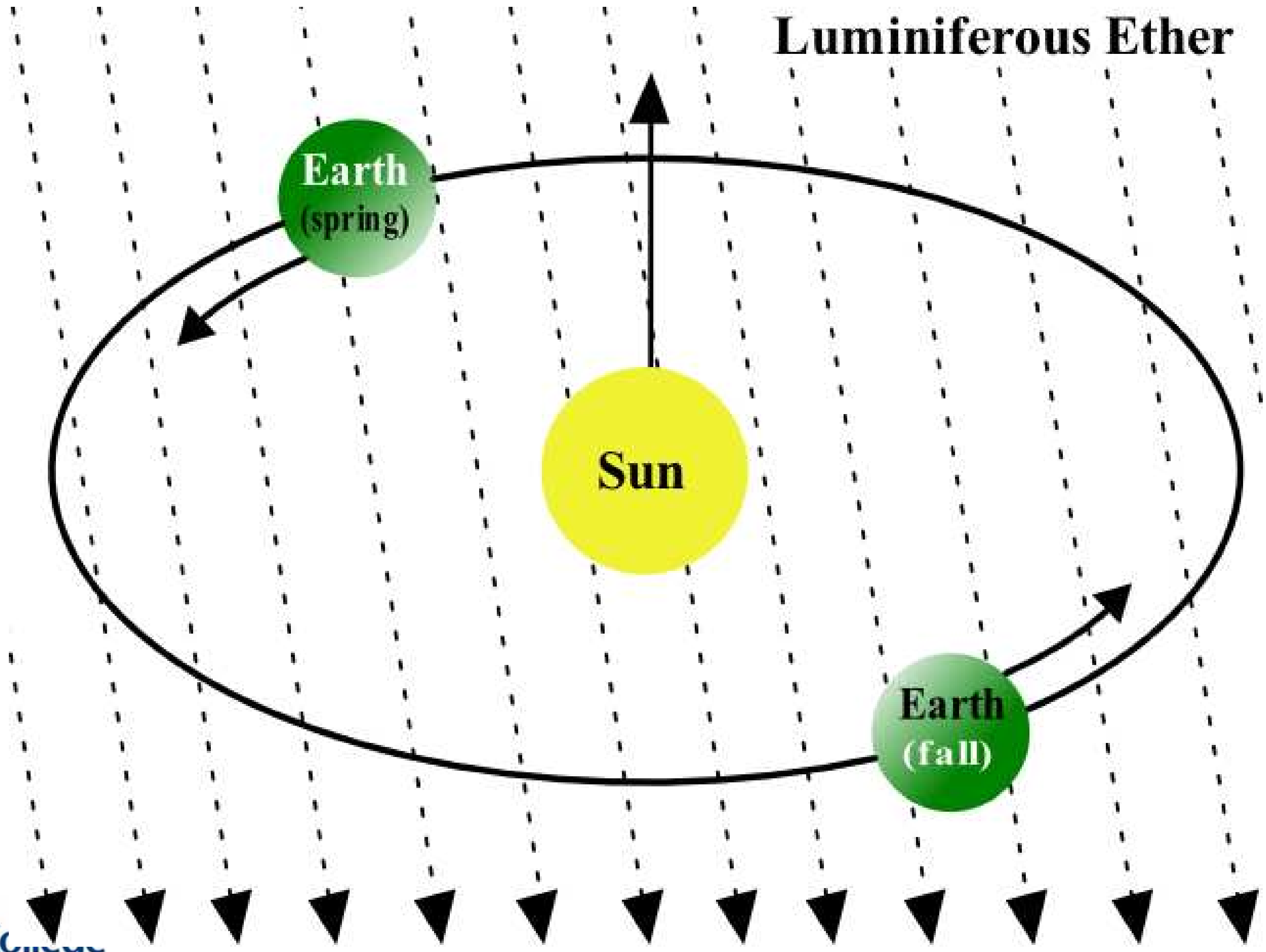
Measurement of the Speed of Light

Can one infer the speed of a plane by measuring the speed of the light it emits?

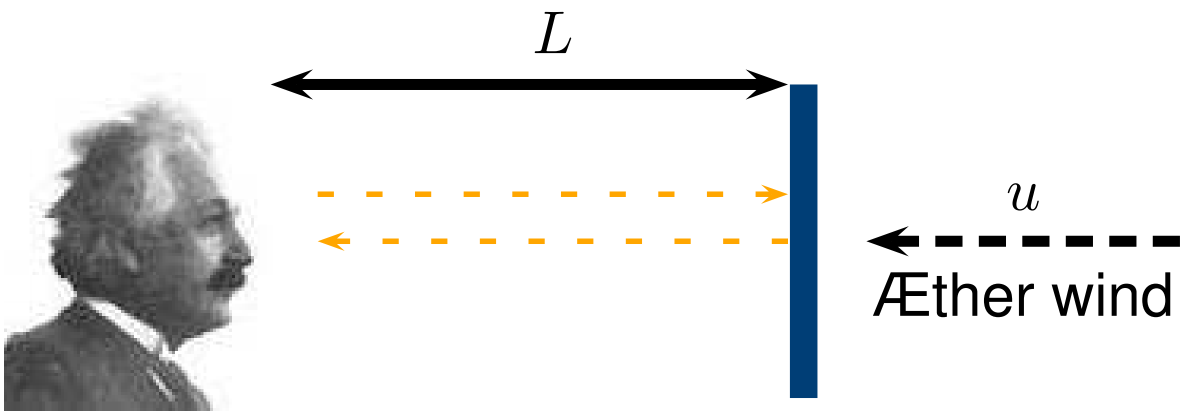


Is the speed of light constant relative to the emitting body, or to the medium?

Luminiferous Æther

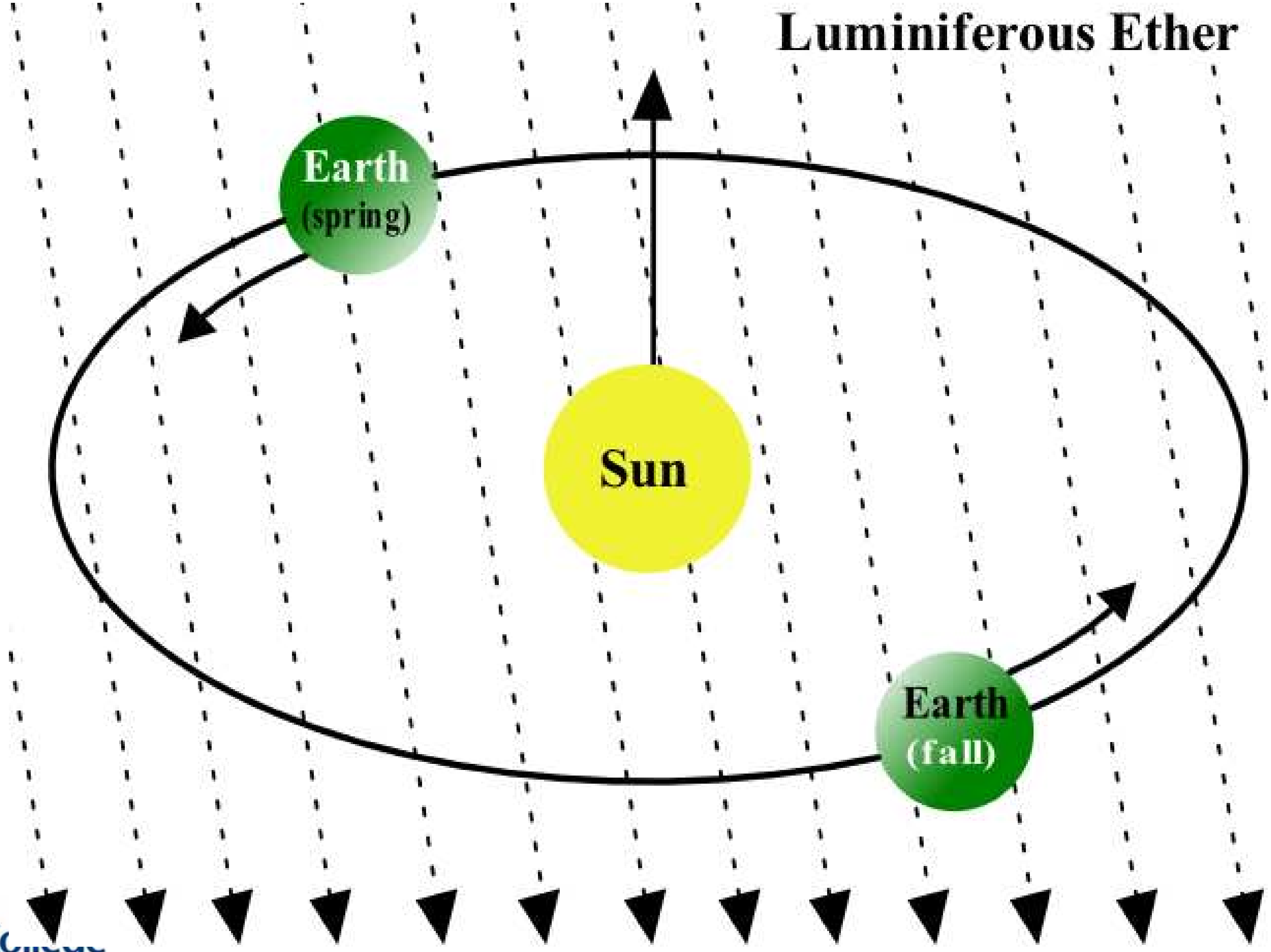


Gedankenexperiment

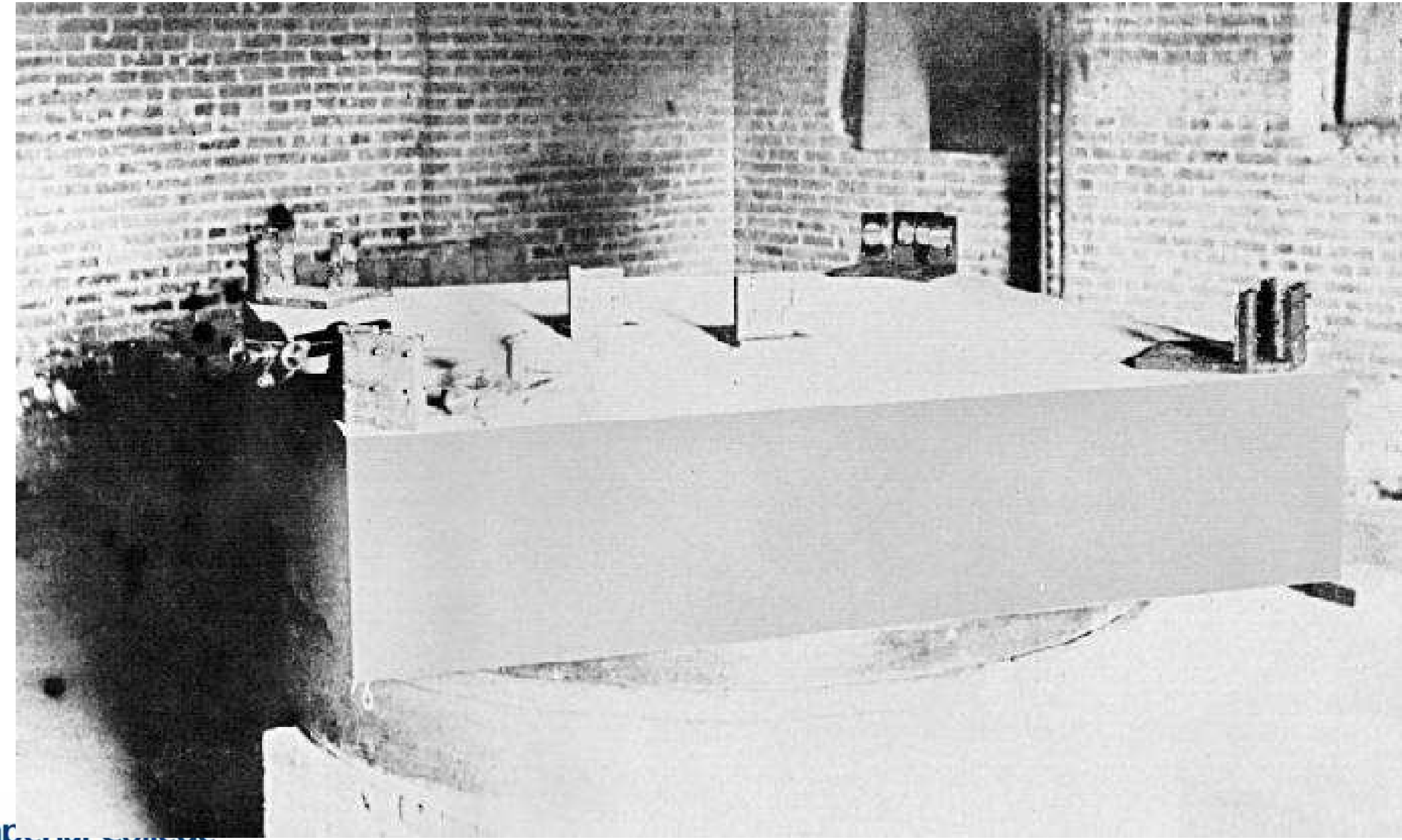


No experimental test provides any way to distinguish an inertial frame from another.

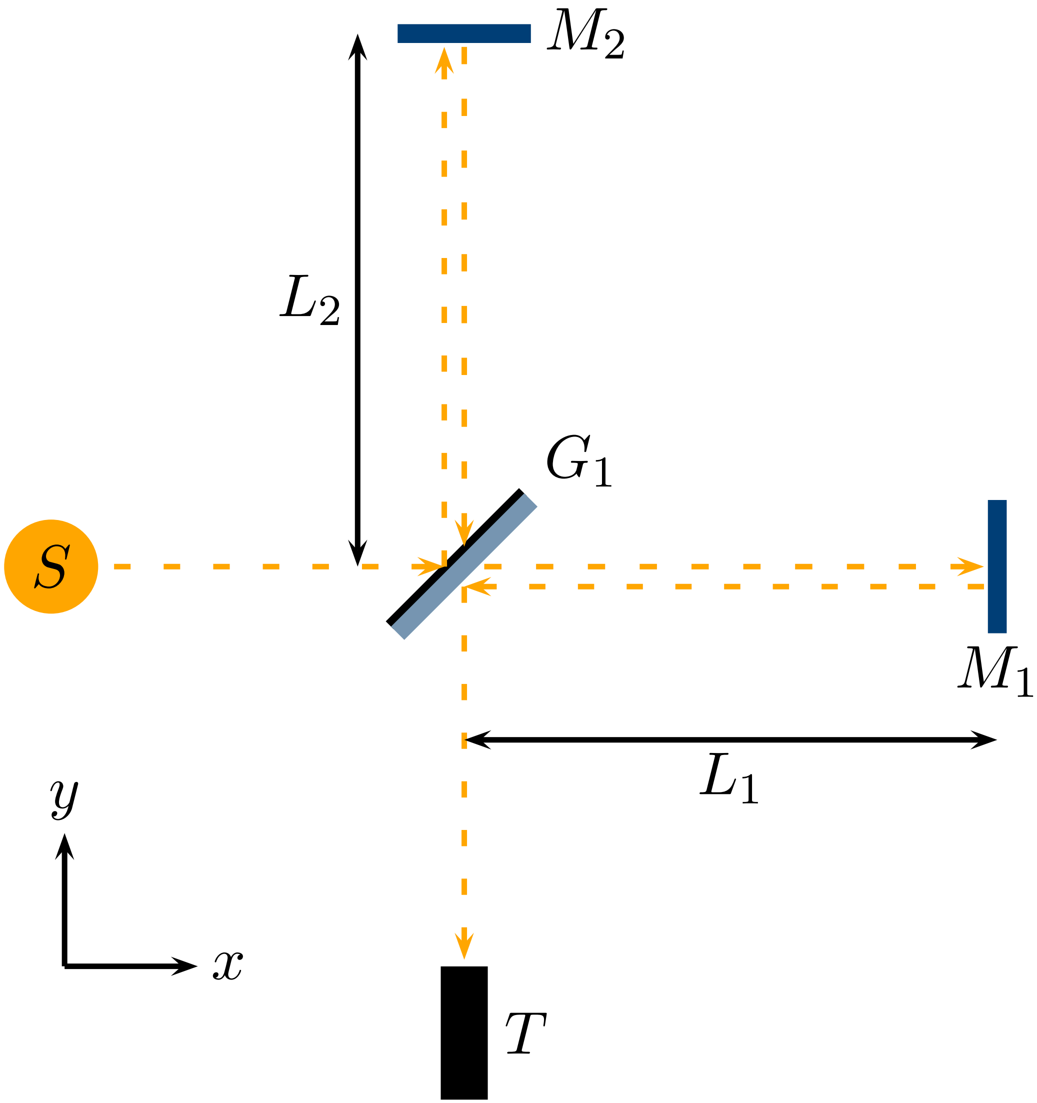
Luminiferous Æther



The Michelson-Morley experiment

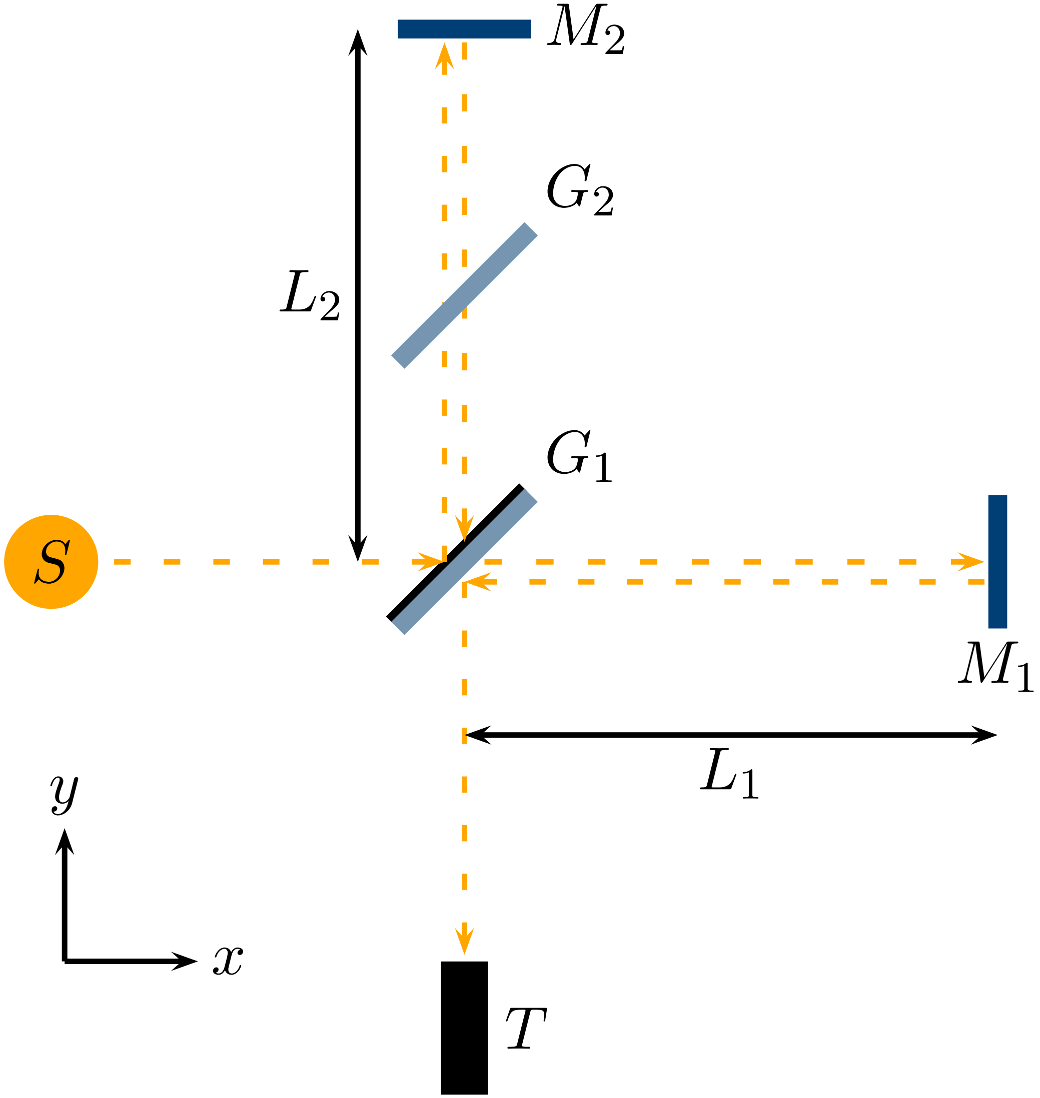


The Michelson-Morley experiment



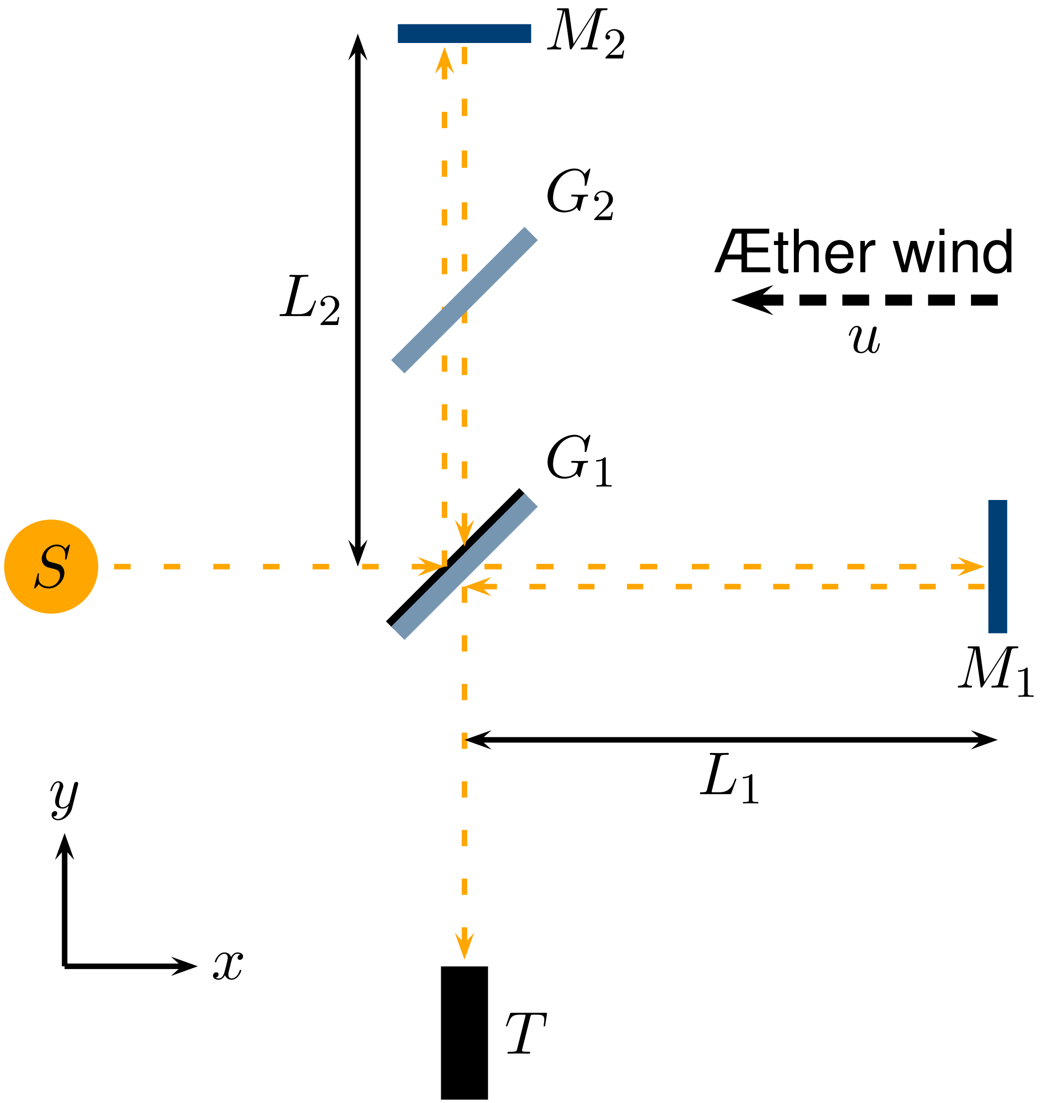
- Experiment to measure differences in speed of light due to æther wind

The Michelson-Morley experiment



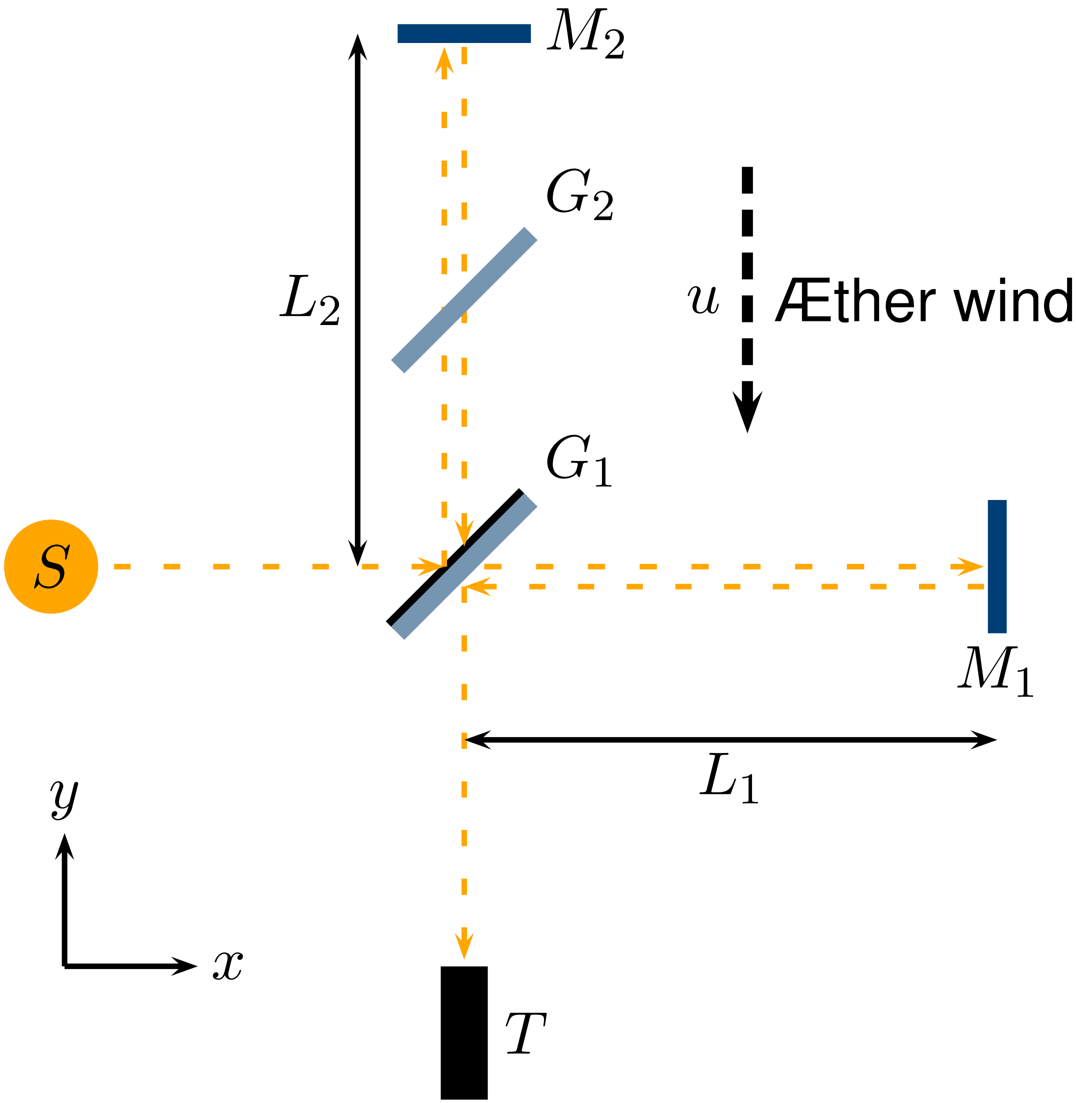
- Experiment to measure differences in speed of light due to æther wind
- Need to make sure all optical paths are of same lengths

The Michelson-Morley experiment



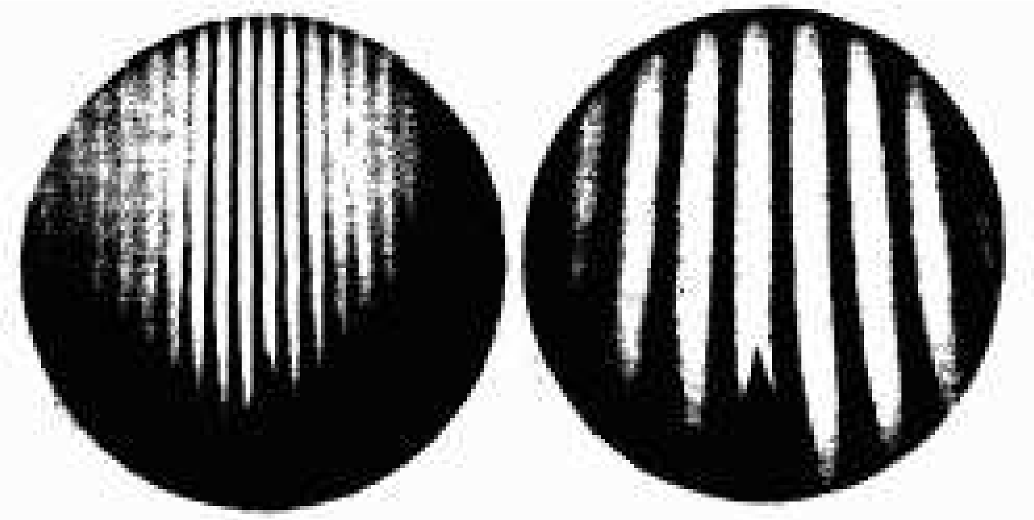
- Experiment to measure differences in speed of light due to æther wind
- Need to make sure all optical paths are of same lengths
- When wind blows from right, horizontal path takes more time

The Michelson-Morley experiment



- Experiment to measure differences in speed of light due to æther wind
- Need to make sure all optical paths are of same lengths
- When wind blows from right, horizontal path takes more time
- When wind blows from top vertical path takes more time

The Michelson-Morley experiment



- Experiment to measure differences in speed of light due to æther wind
- Need to make sure all optical paths are of same lengths
- When wind blows from right, horizontal path takes more time
- When wind blows from top vertical path takes more time
- Can the difference be seen?