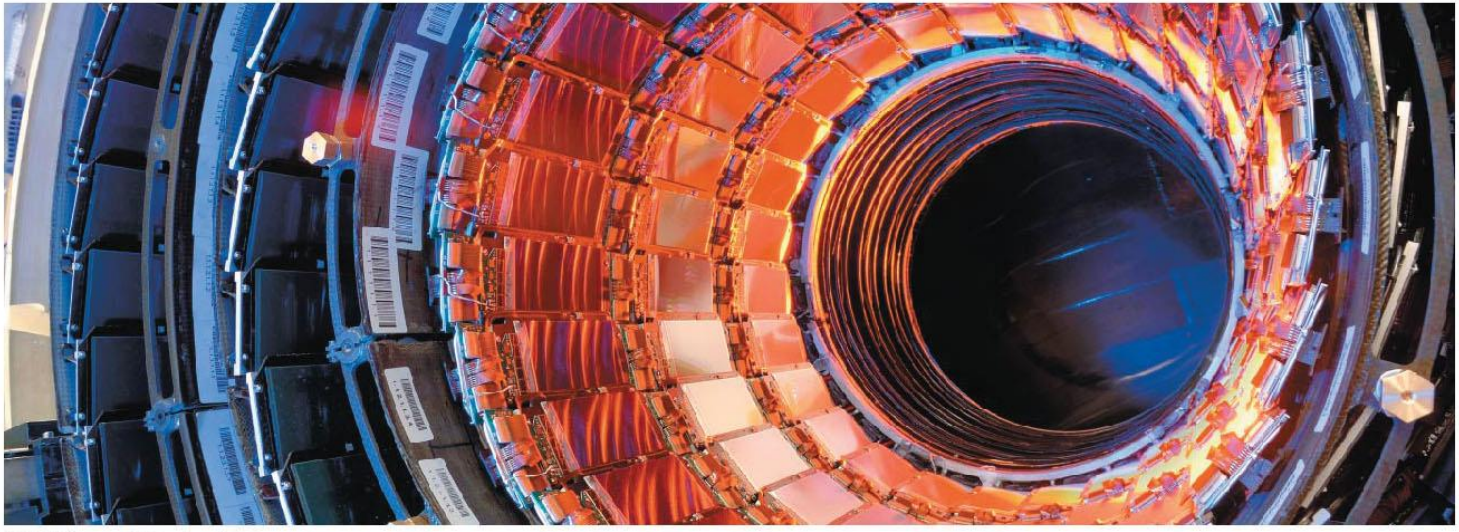
Chapter 36 – Relativity

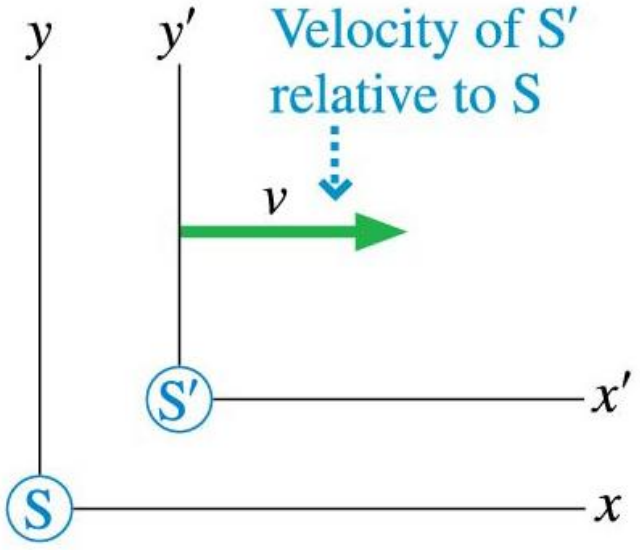
- Reference frames, events, measurements, space-time diagrams
- Postulates of special relativity, impact on simultaneity
- Time dilation, space contraction, and Lorentz transformations
- Relativistic momentum and energy



What is an inertial reference frame?

Inertial reference frames are reference frames that move relative to each other with **constant velocity**.

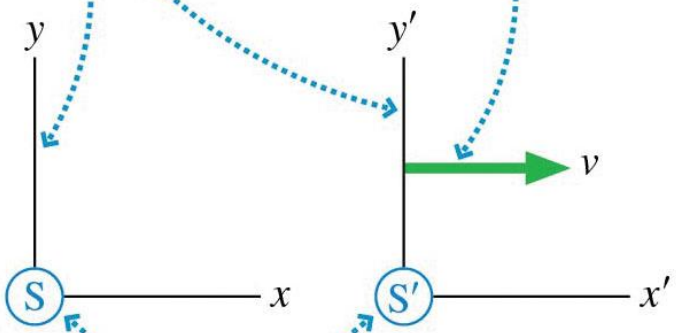
- You'll learn to work with the **positions** and **times** of **events**.
- All the **clocks** in an inertial reference frame are **synchronized**.



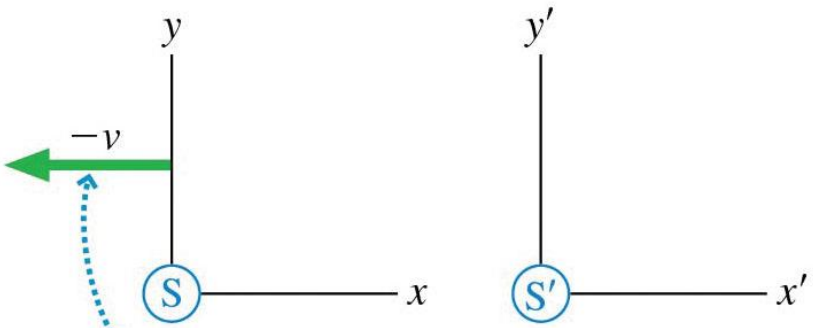
« **LOOKING BACK** Section 4.3 Relative motion

The axes of S and S′ have the same orientation.

Frame S′ moves with velocity v relative to frame S, parallel to the x- and x'-axes.

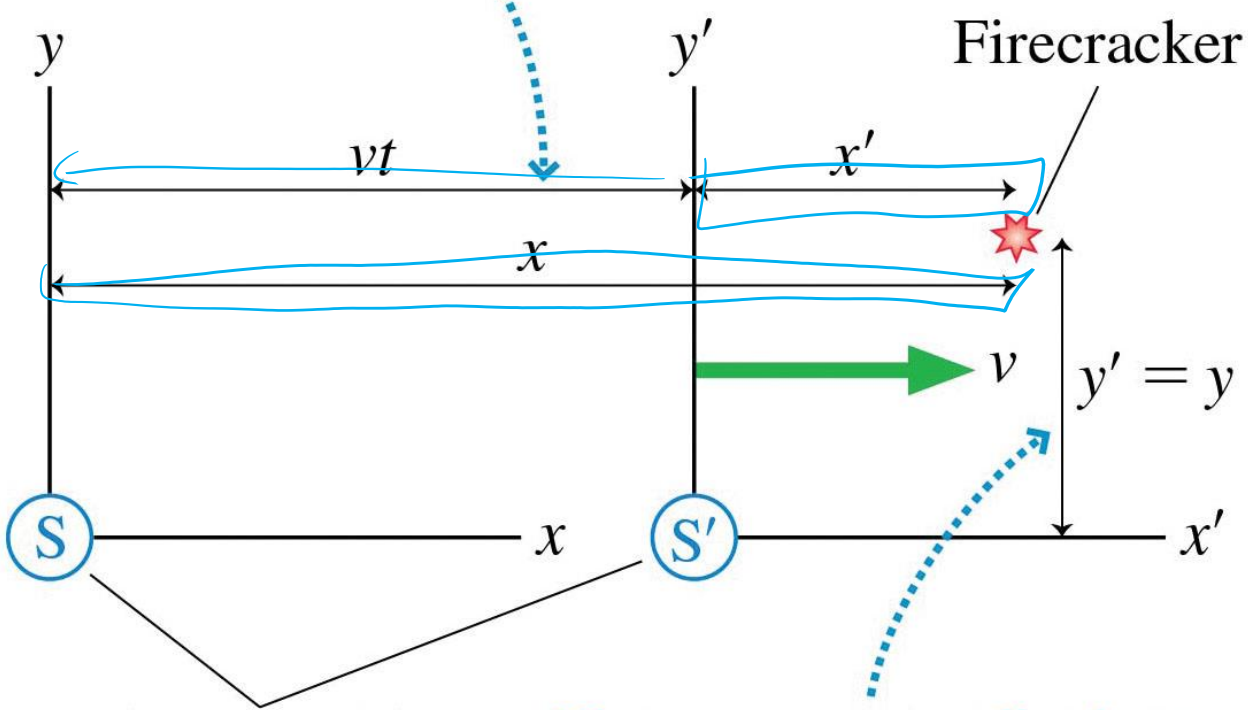


The origins of S and S′ coincide at $t = 0$.



Alternatively, frame S moves with velocity $-v$ relative to frame S′.

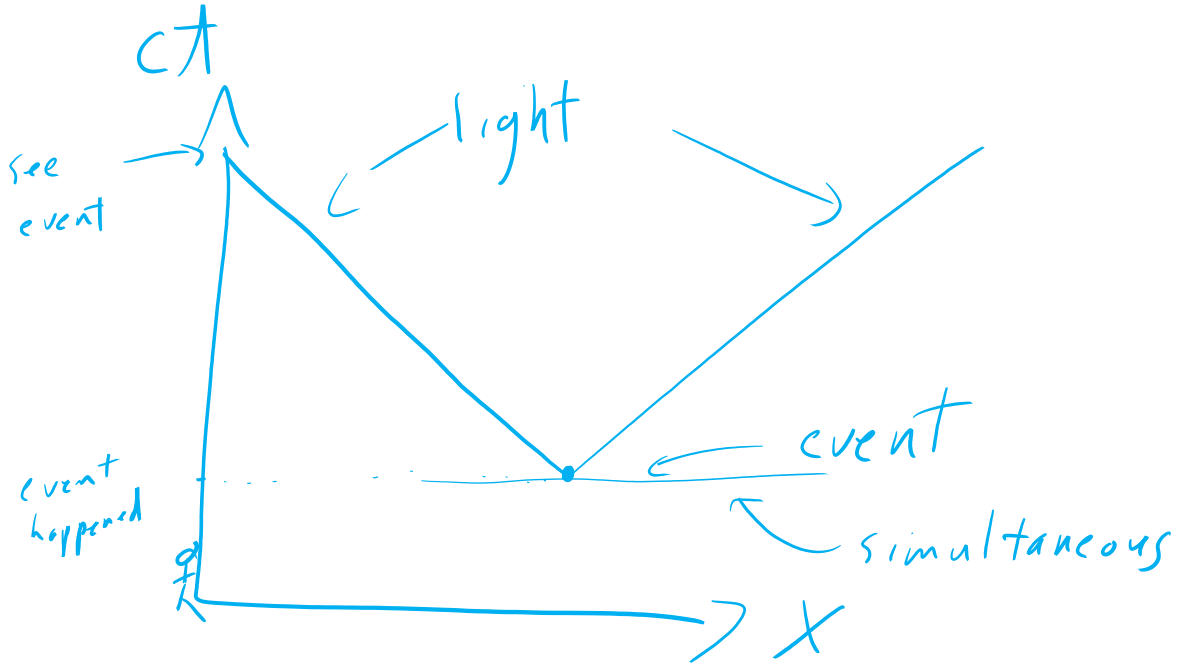
At time t, the origin of S′ has moved distance vt to the right. Thus $x = x' + vt$.



Origins coincide at $t = 0$.

Distances perpendicular to the motion are not affected. Thus $y' = y$ and $z' = z$.

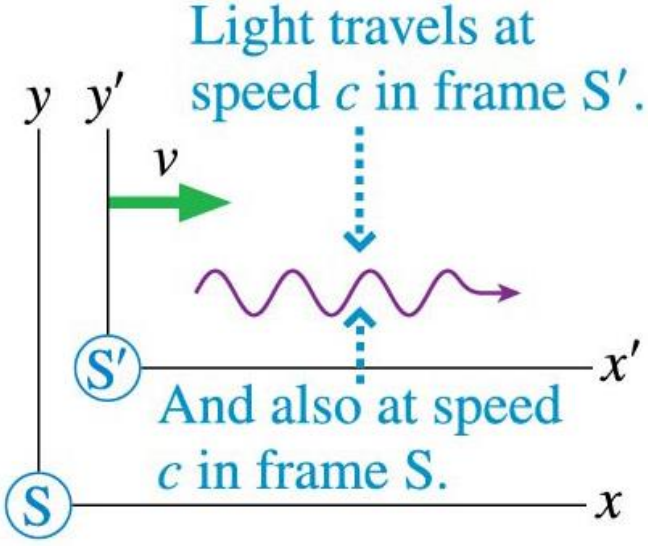
Space-time diagrams



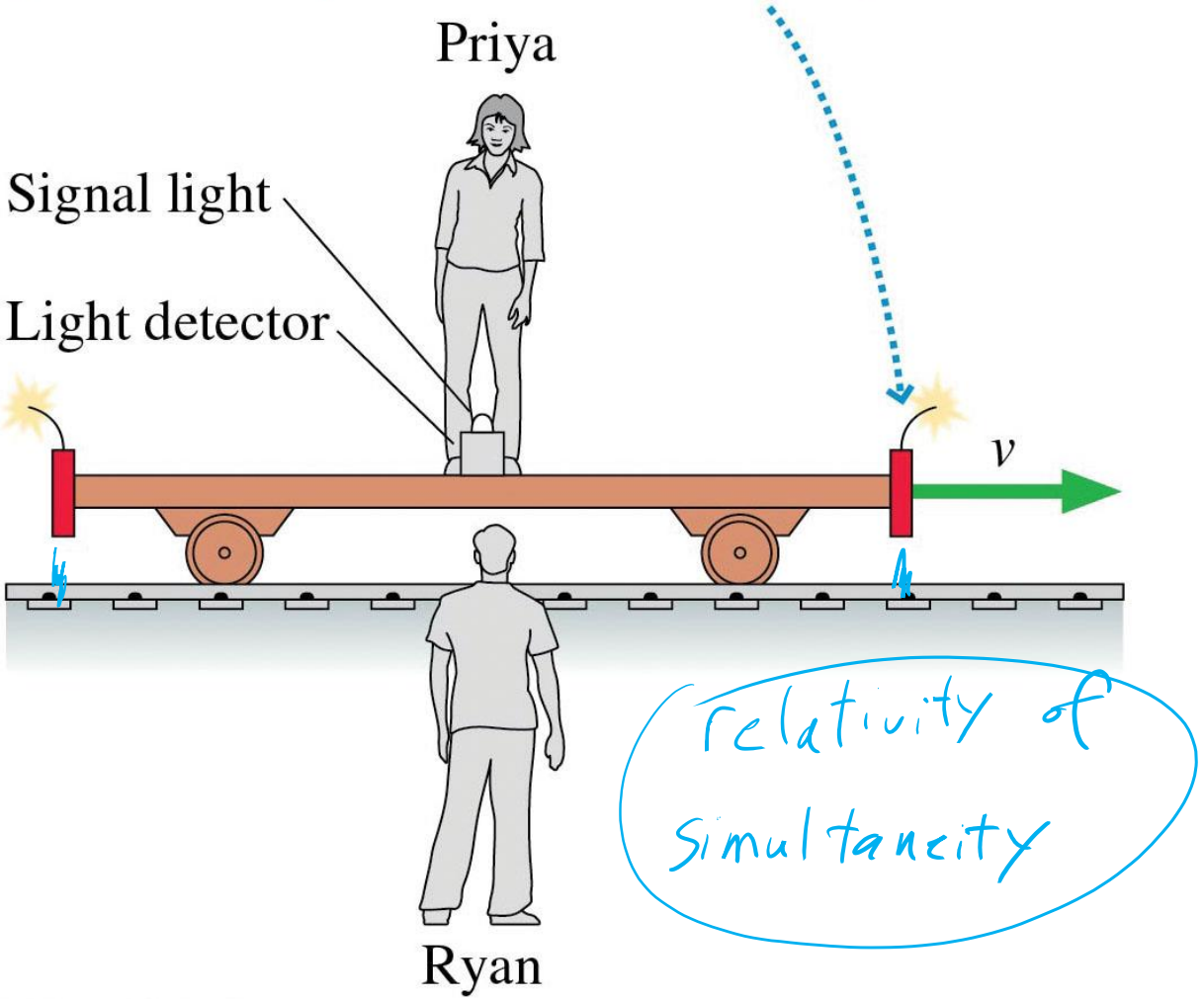
What is relativity about?

Einstein's **theory of relativity** is based on a simple-sounding principle: The laws of physics are the same in all inertial reference frames. This leads to these conclusions:

- **Light travels at the same speed** c in all inertial reference frames.
- No object or information can travel faster than the speed of light.

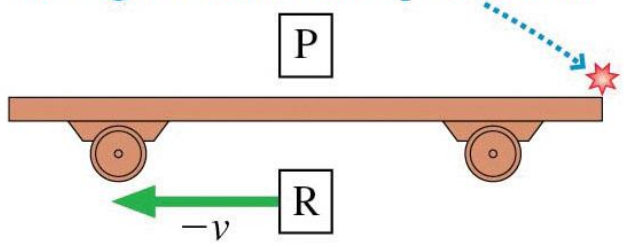


The firecrackers will make burn marks on the ground at the positions where they explode.



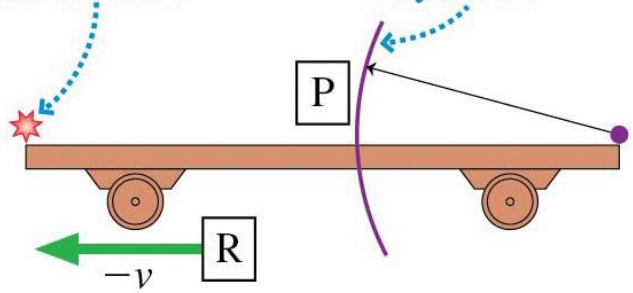
relativity of simultaneity

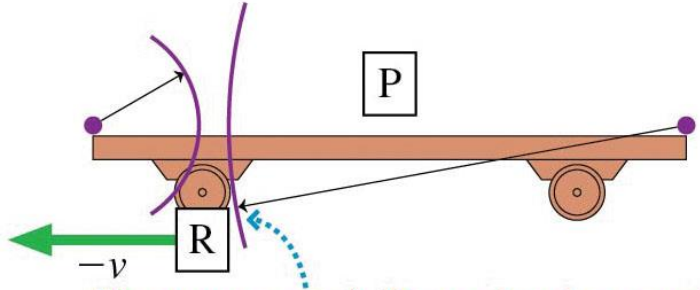
The right firecracker explodes first.



The left firecracker explodes later.

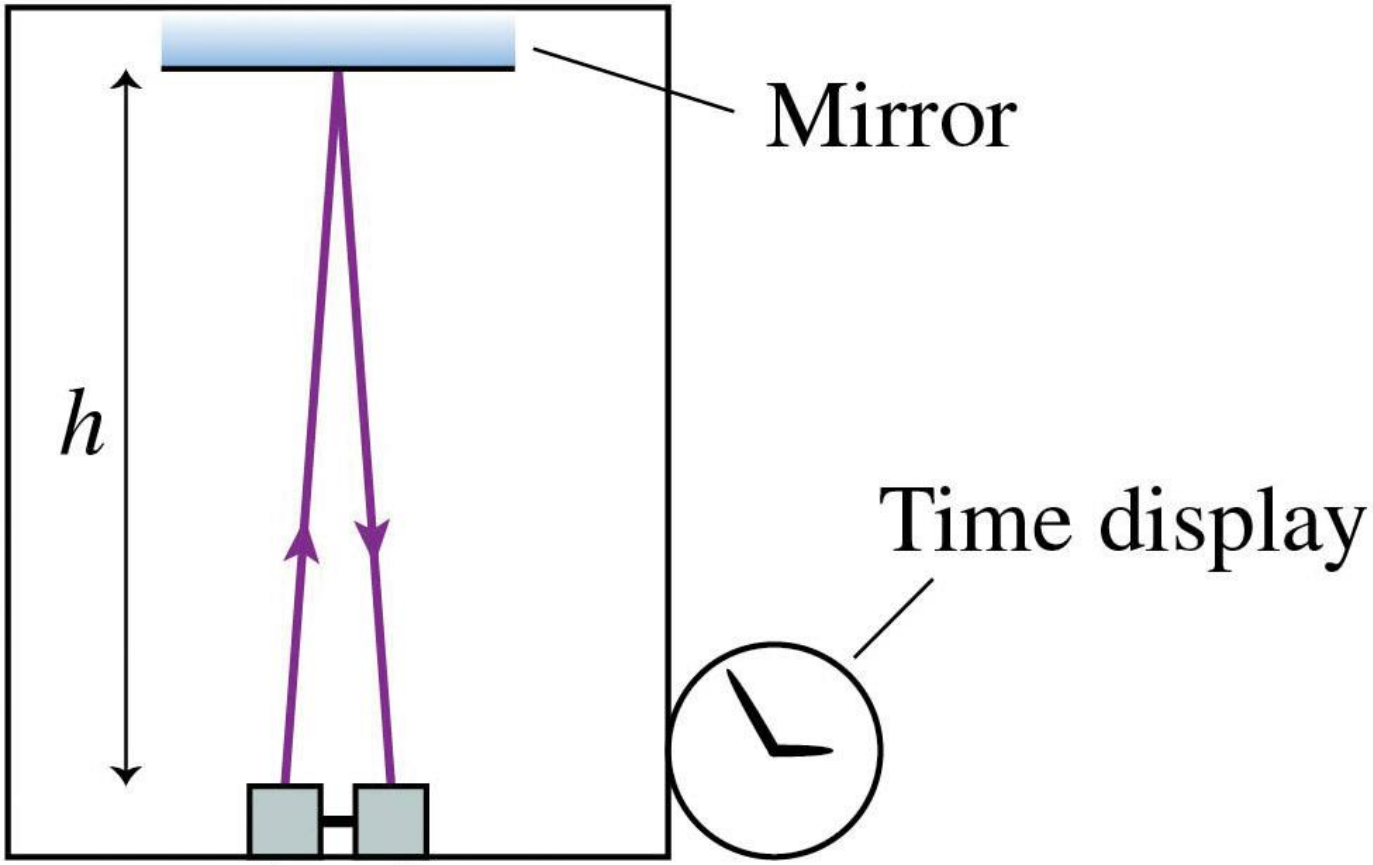
The right wave reaches Priya first.

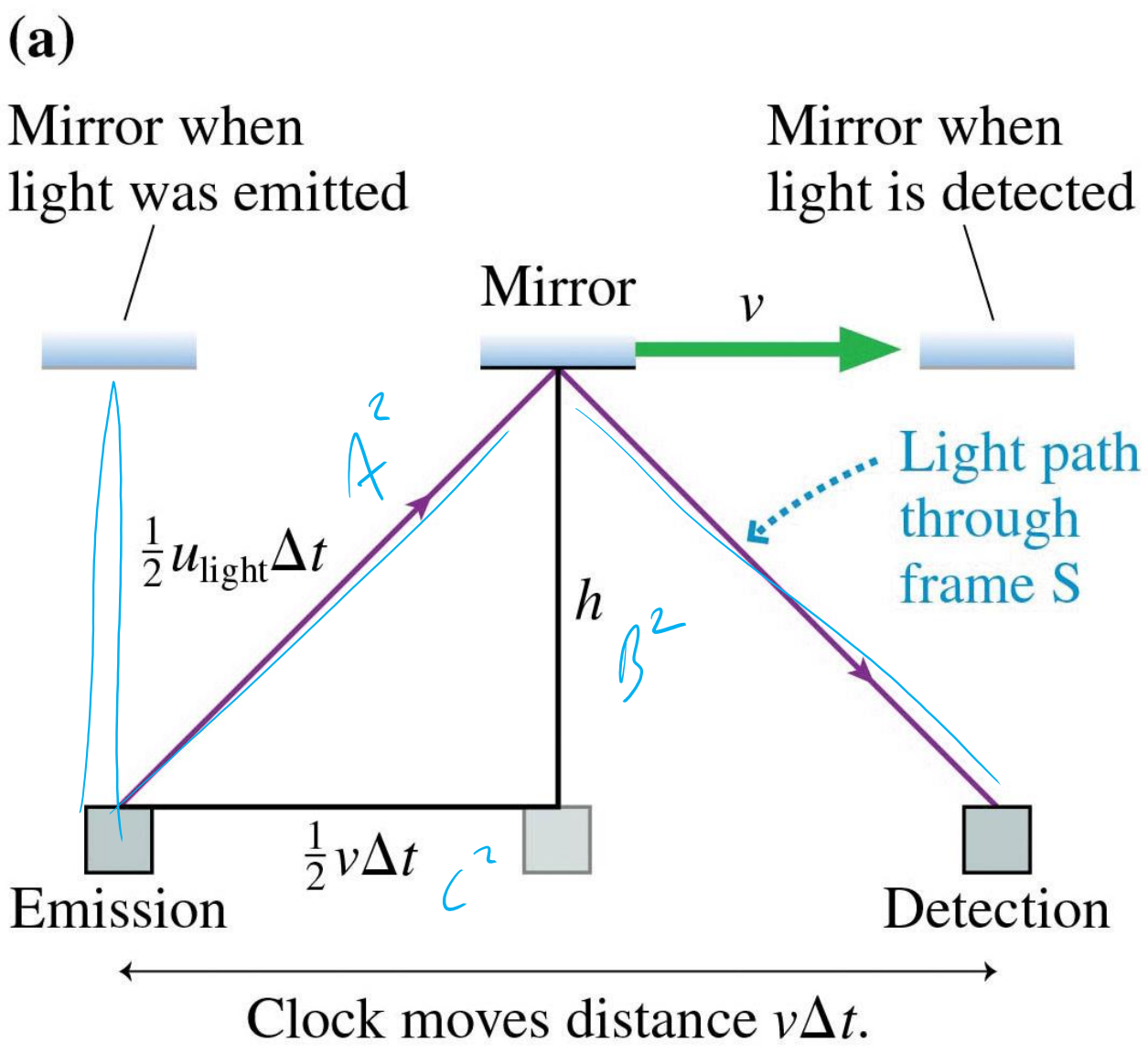




The waves reach Ryan simultaneously.
The left wave has not reached Priya.

(a) A light clock



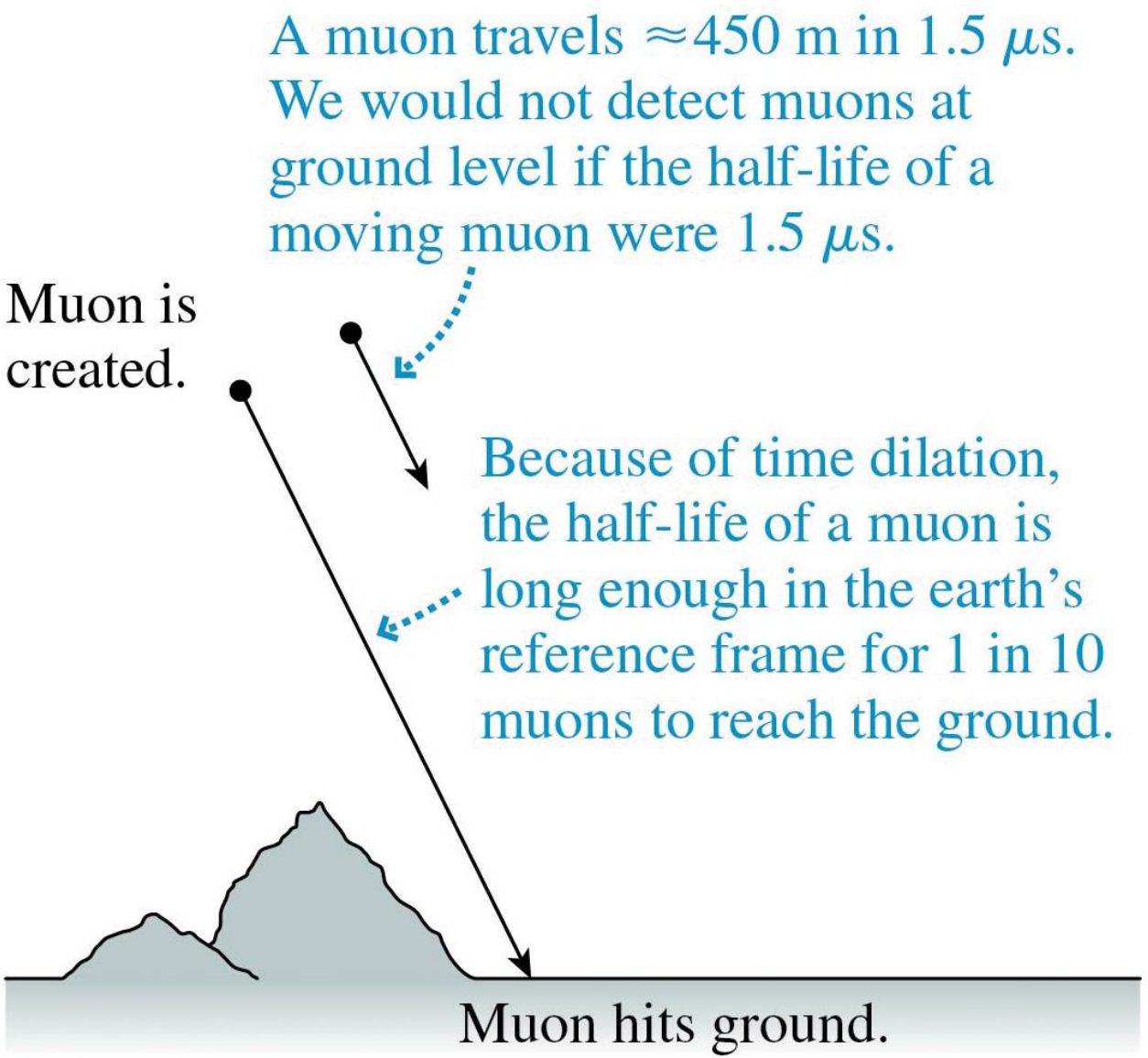


Proper time

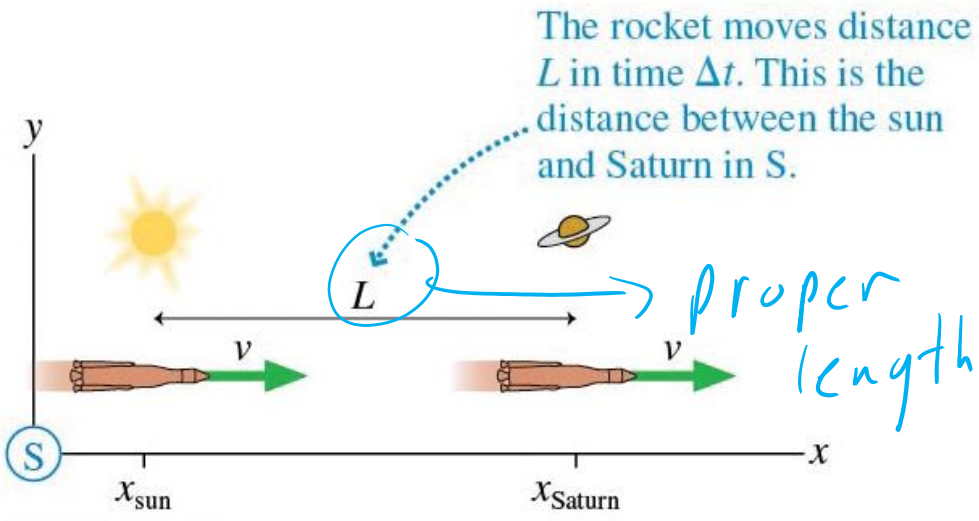
$$\Delta t = \Delta\tau\,\gamma$$

$$\gamma = \frac{1}{\sqrt{1 - v^2/c^2}}$$

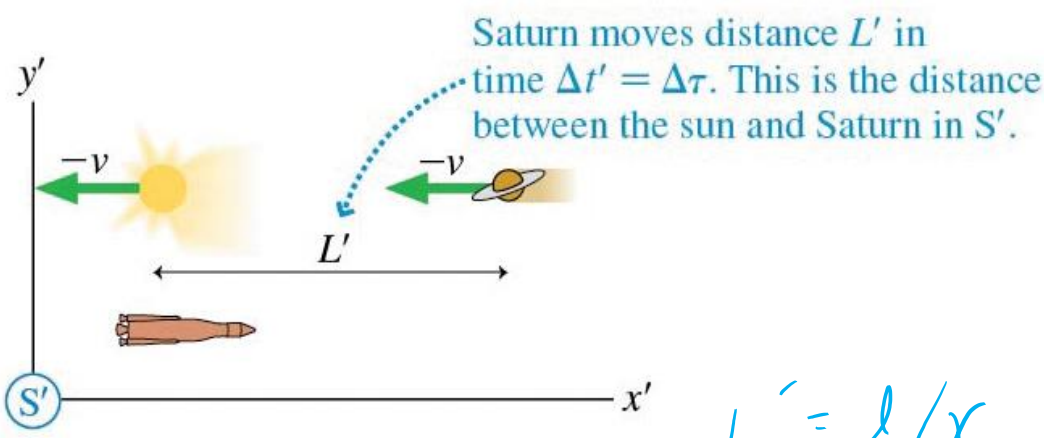
$\gamma \geq 1$ time dilation



(a) Reference frame S: The solar system is stationary.



(b) Reference frame S′: The rocket is stationary.



proper length

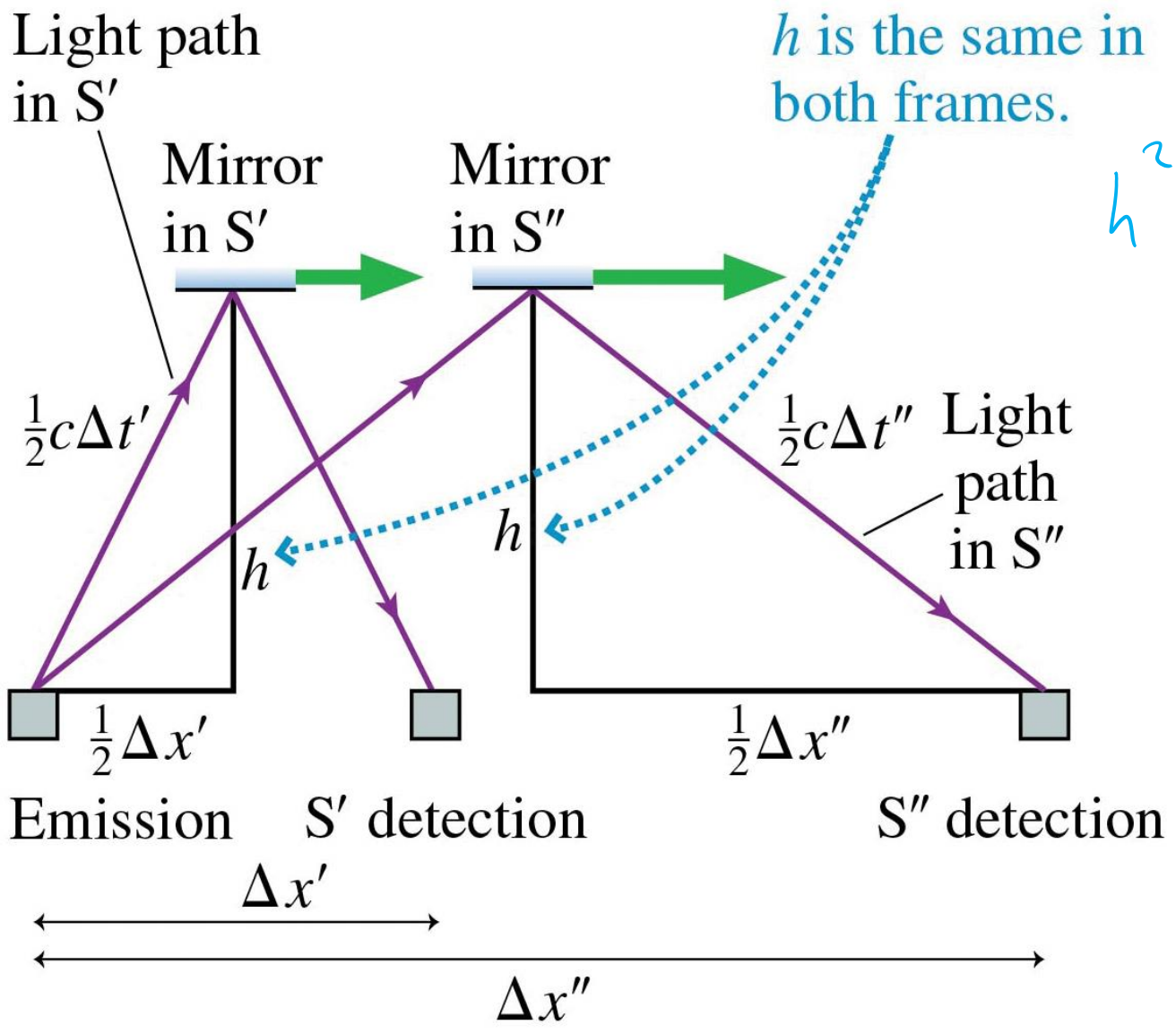
$L' = l/\gamma$

$v = \frac{L}{\Delta t} = \frac{L'}{\Delta\tau} = \frac{L'}{\Delta t/\gamma}$

$L = \gamma L'$

l proper length

$\Delta\tau = \Delta t/\gamma$



$$h^2 = \left(\tfrac{1}{2}c\Delta t'\right)^2 + \left(\tfrac{1}{2}\Delta x'\right)^2$$

$$= \left(\tfrac{1}{2}c\Delta t''\right)^2 + \left(\tfrac{1}{2}\Delta x''\right)^2$$

$$ds^2 = c^2 dt^2 - dx^2$$

c invariant

The **Lorentz transformations** transform spacetime coordinates and velocities between reference frames S and S′.

$$x' = \gamma(x - vt) \qquad x = \gamma(x' + vt')$$
$$y' = y \qquad y = y'$$
$$z' = z \qquad z = z'$$
$$t' = \gamma(t - vx/c^2) \qquad t = \gamma(t' + vx'/c^2)$$
$$u' = \frac{u - v}{1 - uv/c^2} \qquad u = \frac{u' + v}{1 + u'v/c^2}$$

where u and u' are the x- and x'-components of an object's velocity.

$$\beta = v/c \quad \text{and} \quad \gamma = 1/\sqrt{1 - v^2/c^2} = 1/\sqrt{1 - \beta^2}$$

$u' = c$

$u = \dfrac{c + v}{1 + cv/c^2} = \dfrac{c + v}{1 + v/c} = c = u'$

$x_R' - x_L' = \ell = \gamma(x_R - vt) - \gamma(x_L - vt)$

$\ell = \gamma(x_R - x_L) = \gamma L$

$L = \ell/\gamma$