Bell's spaceships in free fall

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Gödel solution

Example 0
Example 1
Remark
Example 2
Example 3

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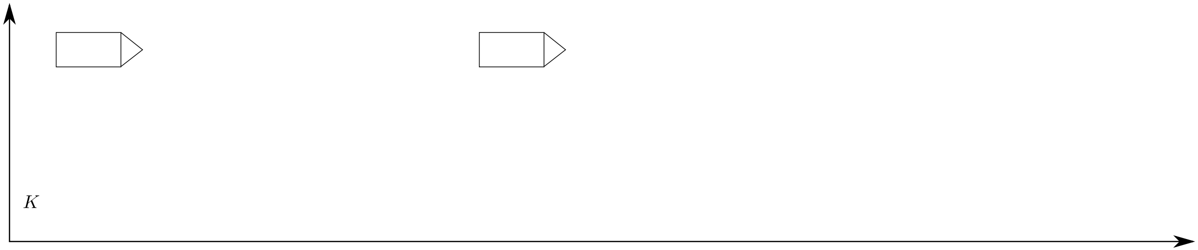
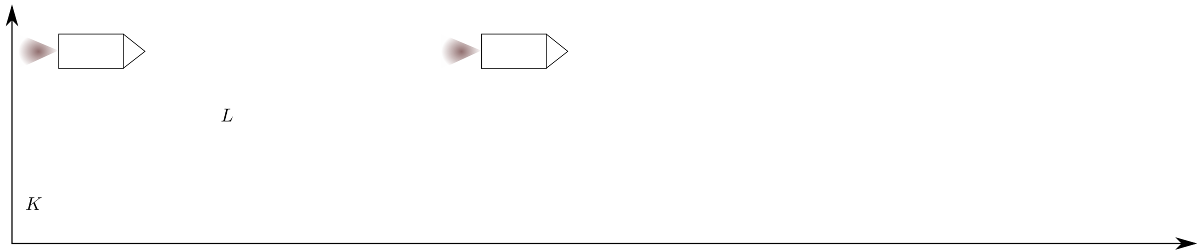


John S. Bell: How to teach special relativity, *Progress in Scientific Culture* 1, 1976



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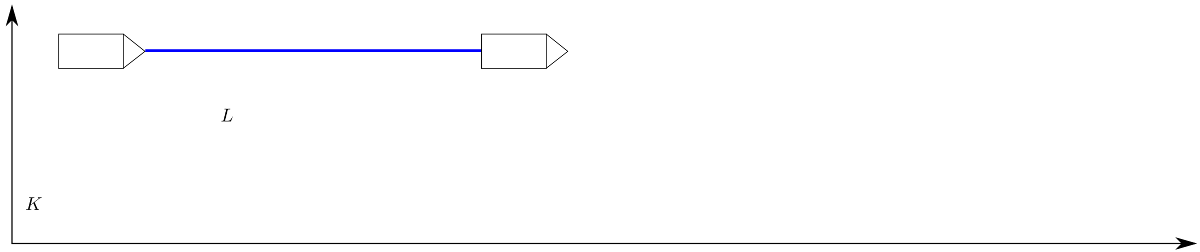

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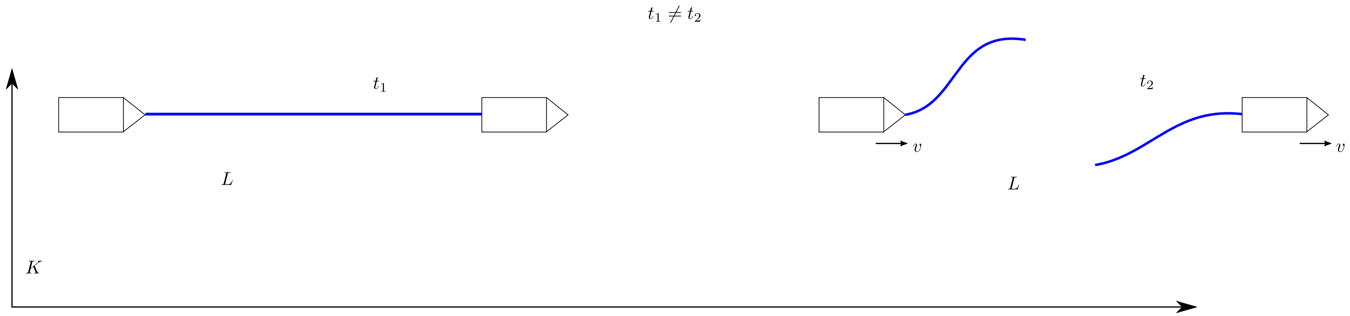

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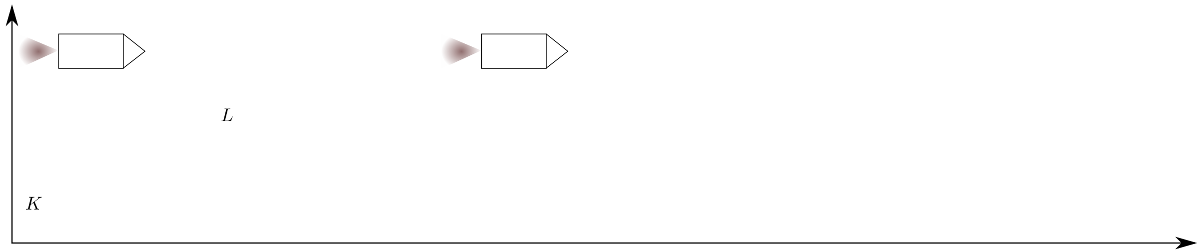
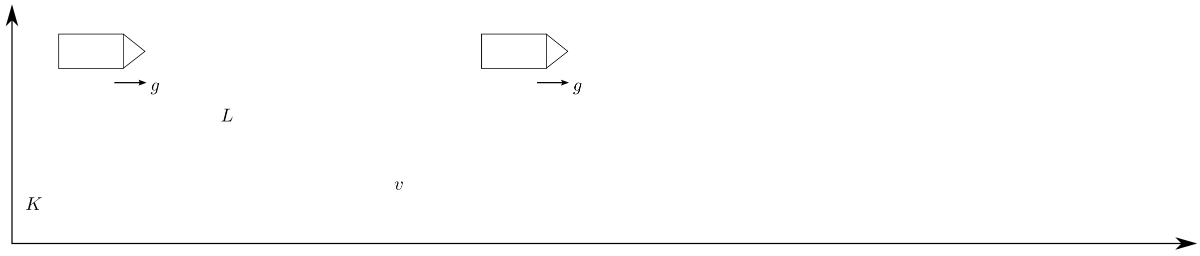
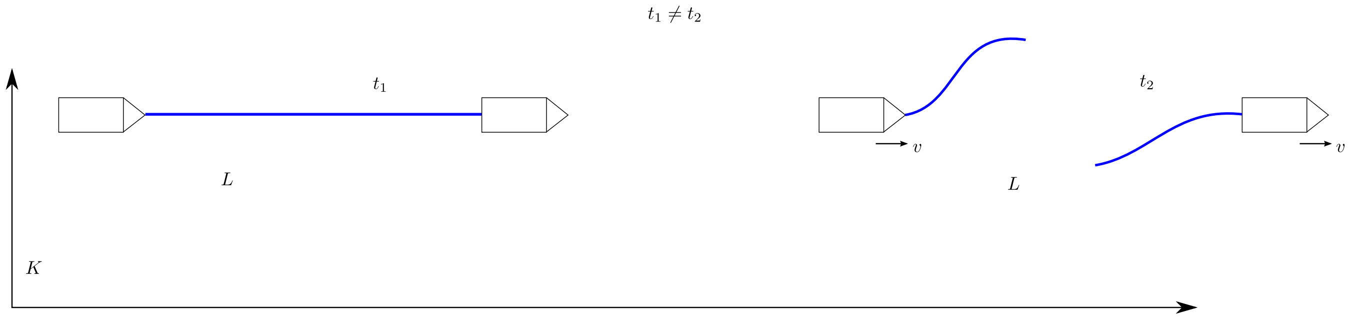

L
K

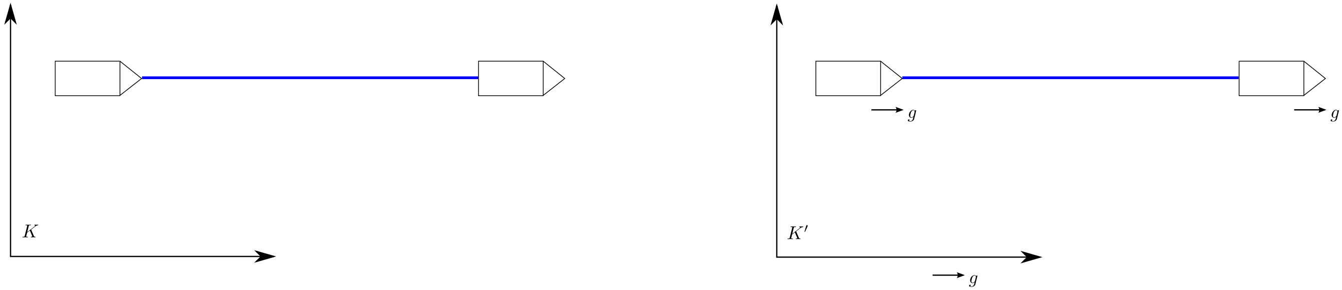


g
g
L
v
K



$t_1 \neq t_2$
t_1
L
K
v
L
t_2
v

What about the equivalence principle?


K
K′
g
g
g

There is a contradiction between the answer based on the equivalence principle and the answer based on the relativistic effects as accounted for in a single inertial frame. Which one is the correct answer?

What is a uniform gravitational field in general relativity?

F. Rohrlich: The principle of equivalence, *Annals of Physics* 22, 1963:

$$ds^2 = A\,(x)\,dt^2 - B\,(x)\,dx^2 - C\,(x)\,dy^2 - D\,(x)\,dz^2$$

$$R_{\kappa\lambda\mu\nu} = 0$$

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For example, there is a solution of these equations whose geodesics correspond to *hyperbolic motion* satisfying[1]

$$\frac{d}{dt}\left(\frac{m\mathbf{v}}{\sqrt{1-\frac{v^2}{c^2}}}\right) = m\mathbf{g}$$

in the given coordinate system.

[1] m is the rest mass of a test particle moving along the geodesic.

What is a uniform gravitational field in general relativity?

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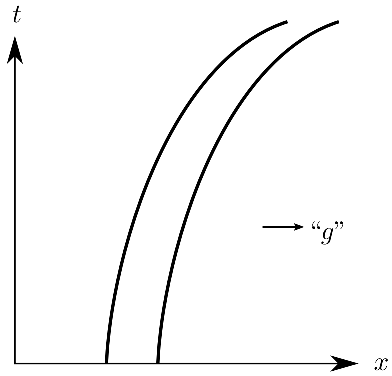
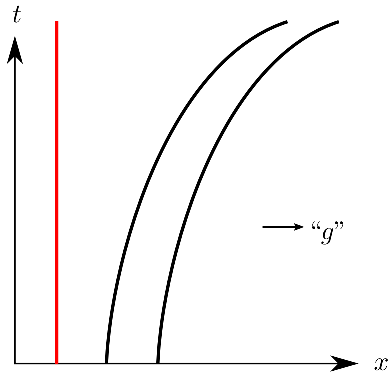
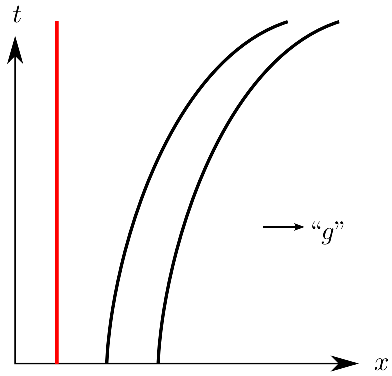


- Since $R_{\kappa\lambda\mu\nu} = 0$, there is no geodesic deviation, and initially parallel geodesics preserve their separation
- For an observer in "free fall" parallel geodesics are parallel straight lines
- The spaceships move on parallel geodesics, and so a co-moving observer will see them at rest, and since her frame is inertial she will not see the thread break



- The observer “supported” in the gravitational field is not inertial, so Bell’s argument cannot be formulated



- The observer "supported" in the gravitational field is not inertial, so Bell's argument cannot be formulated
- (If one wants to know what the "supported" observer sees, one can employ the equivalence principle: the thread will not break)

The thread will not break.

The thread will not break. Is it really so?

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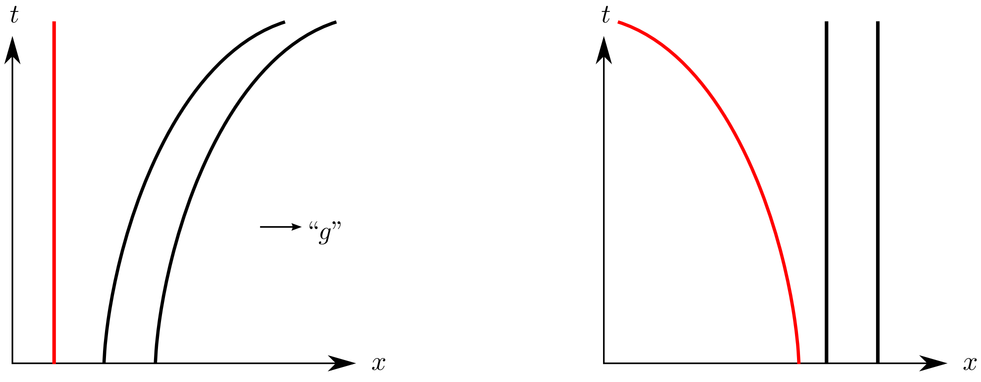

- It is in fact not general relativity that resolves the contradiction, for the argument equally well goes through in the geometrized version of Newtonian gravity
- But the geometrized version is just a reformulation of the original Newtonian theory. How can a mere reformulation cause a thread break or not break?
- More precisely, how is it possible that the relativistic effects contradict to one version but not the other one, while the two versions are equivalent theories?

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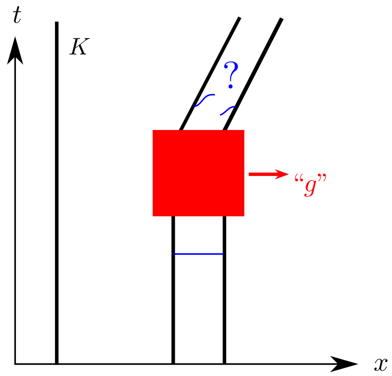
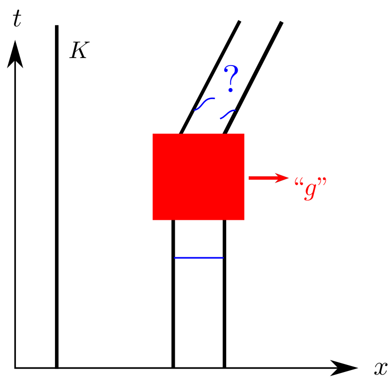
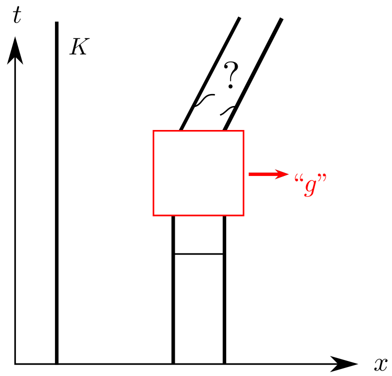


There are two plausible options: after the acceleration, the distance of the spaceships is either 1) Lorentz contracted or 2) it is the same as initially—as seen by K



There are two plausible options: after the acceleration, the distance of the spaceships is either 1) Lorentz contracted or 2) it is the same as initially—as seen by K

1) As seen by K, Lorentz contraction is an electromagnetic effect—as per Bell's reasoning. How does any theory of gravity know about it?



There are two plausible options: after the acceleration, the distance of the spaceships is either 1) Lorentz contracted or 2) it is the same as initially—as seen by K

2) As seen by K, the thread must break. When does it break?

   a) It can't break in the interior of the red region, as in it $R_{\kappa\lambda\mu\nu} = 0$

   b) There can be curvature at the boundary of the red region where the spaceships enter. But the thread can't break there since

$$\Delta v = \int_{\Delta t \approx 0} a(t) dt \approx 0$$

   as seen by K

Which one of these options obtains?

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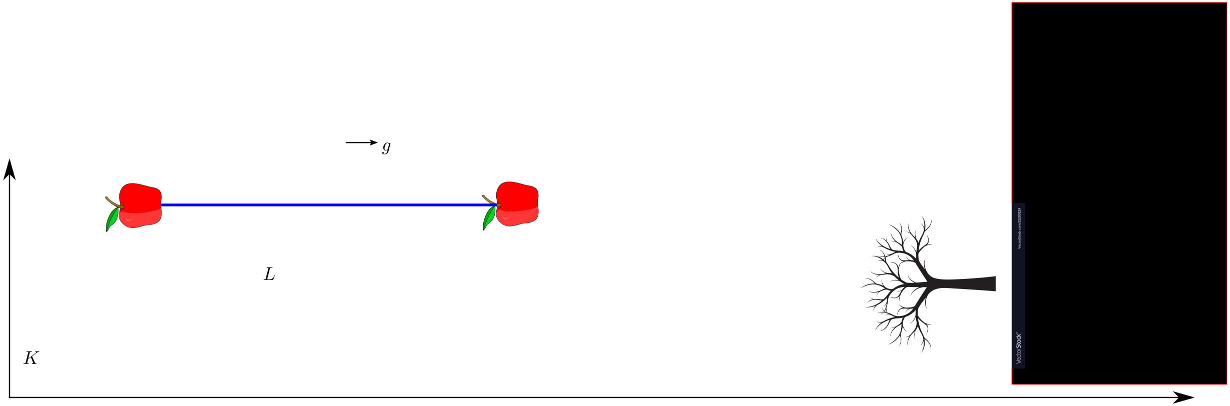
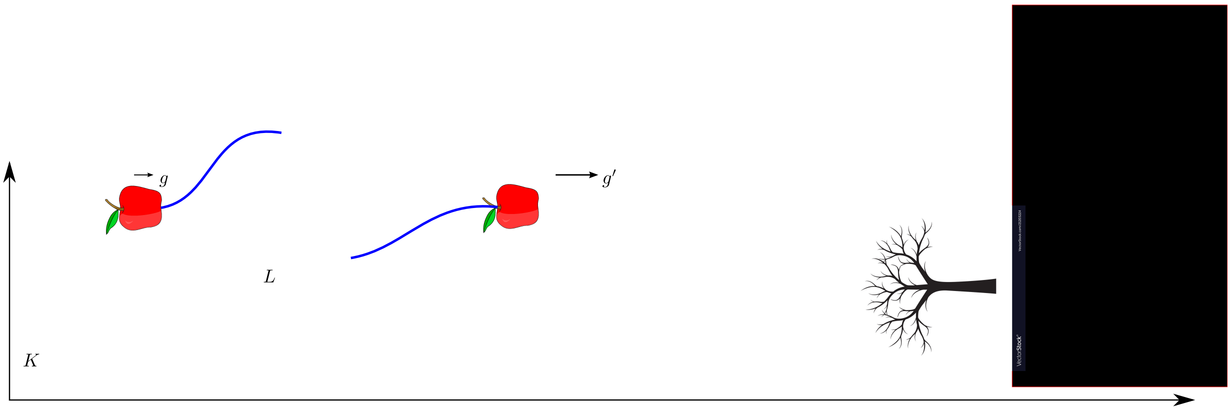
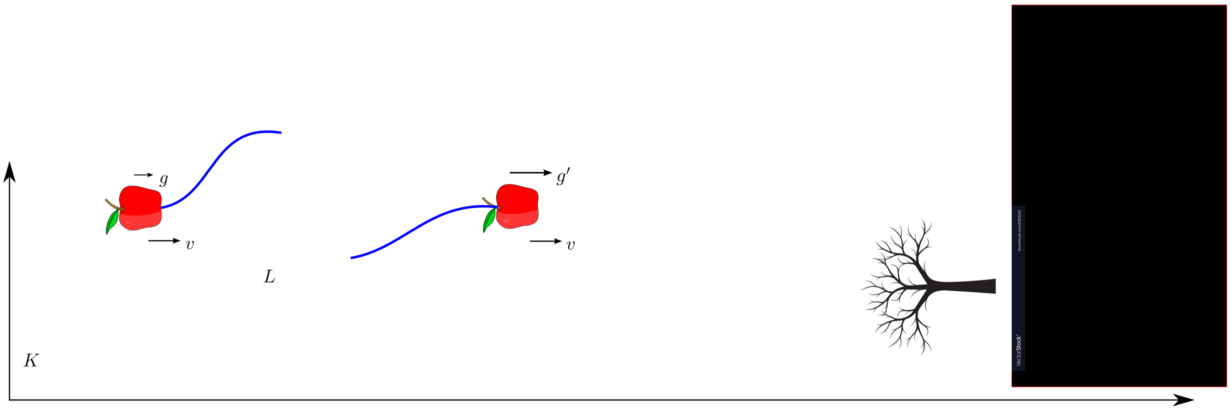

g
L
K


g
g'
L
K



If there appears stress due to Lorentz contraction, in addition to the tidal forces, then the thread will break at different heights depending on the initial velocity of the apples—all as seen from the Earth

Is there such an effect?