

# Model Solutions for Final Exam

## Einstein and Relativity; March 2021

(a) A frame at rest in gravity is equivalent to ... an accelerating frame in deep space. [[General relativistic principle of equivalence.]]

(b) A passenger train travels east at high speed. One passenger is located at the east side of one car, another is located in the west side of that car. In the train's frame, these two passengers cough at the same time. In the Earth's frame ... the passenger at the west side coughs first. [[Relativity of simultaneity – the rear (in this case west) event happens first.]]

(c) Ivan says Veronica's clocks tick slowly, Veronica says Ivan's clocks tick slowly. This is not a logical contradiction because ... two events simultaneous in Ivan's frame may not be simultaneous in Veronica's. [[See the chapter on "He Said, She Said".]]

(d) Ignore the rotation of the earth. Which clock ticks more slowly? The one at the base of the Eiffel Tower. [[General relativistic (or gravitational) time dilation.]]

(e) Veronica speeds by us in her rocket sled at 95% the speed of light, and her heart beats very slowly. Nevertheless, we needn't fear for her life because ... her cells are also respiring slowly.

(f) Mount Rainier and Mount Hood, which are 500 km apart in their rest frame, suddenly erupt at the same time in the reference frame of a seismologist at rest in a laboratory midway between the two volcanoes. An alien spacecraft flying with constant speed  $V = (4/5)c$  from Rainier toward Hood is directly over Mount Rainier when it erupts. In the reference frame of the spacecraft, does Rainier erupt *before*, *after*, or *at the same time* as Hood erupts?

Rainier after Hood. [[Relativity of simultaneity (relativity of synchronization). In the spacecraft's frame, Rainier and Hood are traveling toward the spacecraft. Hood is to the rear, so Hood's clock is set ahead.]]

**Veronica runs down a 1500-foot-long straight track at the uniform speed of  $(3/5)c$  (so that  $\sqrt{1 - (V/c)^2} = 4/5$ ).**

**(g)** How long does Veronica's race take in the Earth's frame?

2500 nan [[because distance = speed  $\times$  time]]

**(h)** In Veronica's frame, how long is the racetrack?

1200 feet [[length contraction]]

**(i)** Veronica passes the start line when the start-line clock reads 030 nan. In Veronica's frame, what does the finish-line clock read when Veronica passes the start line?

930 nan [[Rear clock (finish-line clock) set ahead by

$$\frac{L_0 V}{c^2} = \frac{(1500 \text{ ft})(\frac{3}{5}c)}{c^2} = 900 \text{ nan},$$

and 900 nan ahead of 30 nan is 930 nan.]]

**(j)** How long does Veronica's race take in her own frame?

2000 nan [[You could solve this either through distance = speed  $\times$  time, using the distance from part **(h)**, or through time dilation, using the time from part **(g)**.]]