Instructor Solutions Manual: *Modern General Relativity*

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This document gives the solutions for all problems at the ends of chapters for the first edition of *Modern General Relativity: Black Holes, Gravitational Waves, and Cosmology* by Mike Guidry (Cambridge University Press, 2019). Unless otherwise indicated, literature references, equation numbers, figure references, table references, and section numbers refer to the print version of that book.

1 Introduction

1.1 From Eq. (1.2), the value of γ is infinite if $v = c$, so there is no Lorentz transformation to an inertial frame corresponding to a rest frame for light.

1.2 Since $E = m\gamma$, for a 7 TeV proton,

$$\gamma = \frac{E}{m} = \frac{7 \times 10^{12}\,\text{eV}}{938.3 \times 10^{6}\,\text{eV}} = 7460.$$

Then from the definition of γ,

$$\frac{v}{c} = \sqrt{1 - \frac{1}{\gamma^2}} = 0.999999991.$$

This is a speed that is only about 3 meters per second less than that of light.

1.3 This question is ambiguous, since it does not specify whether the curvature is that of the surface itself (which is called *intrinsic curvature*) or whether it is the apparent curvature of the surface seen embedded in a higher-dimensional euclidean space (which is called the *extrinsic curvature*). In general relativity the curvature of interest is usually intrinsic curvature. Then the sheet of paper can be laid out flat and is not curved, the cylinder is *also flat,* with no intrinsic curvature, because one can imagine cutting it longitudinally and rolling it out into a flat surface, but the sphere has finite intrinsic curvature because it cannot be cut and rolled out flat without distortion. The reason that the cylinder seems to be curved is because the 2D surface is being viewed embedded in 3D space, which gives a non-zero *extrinsic curvature,* but if attention is confined only to the 2D surface it has no *intrinsic curvature*. This is a rather qualitative discussion but in later chapters methods will be developed to quantify the amount of intrinsic curvature for a surface.