# Notes for "GRAVITATION" - MTW

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abc

## 1. GEOMETRODYNAMICS

### 1.1. The parable of the apple

Space tells matter how to move and matter tells space how to curve.

### 1.2. Spacetime with and without coordinates

#### 1.2.1. *Hint for possible different characterization* (*P.*6)

"But with all the daring in the world, how is one to drive a nail into spacetime to mark a point? Happily, nature provides its own way to localize a point in spacetime, as Einstein was the first to emphasize. Characterize the point by what happens there!"

#### 1.2.2. *Hint from idealized limit* (*P.*10)

"A more detailed diagram would show a maze of world line and of light rays and the intersections between them. From such a picture, one can in imagination step to the *idealized* limit: an infinitely dense collection of light rays and of world lines of infinitesimal test particles."

#### 1.2.3. *Hint of breakdown of manifold description* (*P.*12)

"Not so quantum general relativity or 'quantum geometrodynamics'. It predicts violent fluctuations in the geometry at distances on the order of the Planck length,... As nearly as one can estimate these fluctuations give space at small distances a 'multiply connected' or 'foam-like' character."

### 1.3. Weightlessness

#### 1.3.1. *Box* 1.2 (*P.*16)

*a. Lorand von Eötvös* The forces mentioned are shown in Fig. 1, from which we directly observe that the

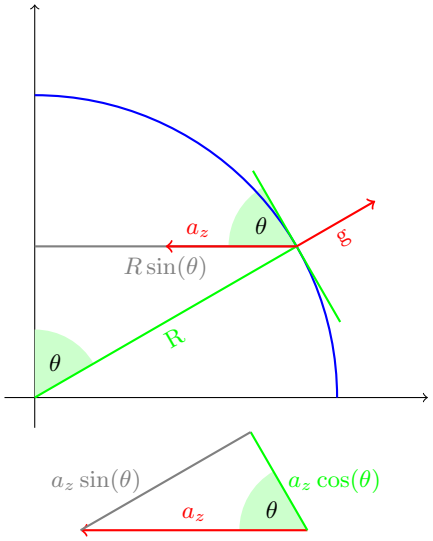


Figure 1: Forces mentioned in Box 1.2, *Lorand von Eötvös*, where $R$ is the radius of the earth and $\theta$ is the angle measured from the north pole

centripetal acceleration is in total

$$a_z = \omega^2 R\sin(\theta),$$

which is *independent* of $g$ in this way of viewing forces ($\omega$ is the rotation speed of the earth). From this we get the northward directed part of $a_z$ to be

$$a_z\cos(\theta) = \omega^2 R\sin(\theta)\cos(\theta).$$

*b. Beall* We know the highest observed energies of the myon to be

$$E_\mu = 1\cdot 10^{13}\,\text{eV}.$$

While the upper threshold is mentioned to be

$$E_{\text{thresh}} = 1\cdot 10^3 mc^2$$

. If now the myon were to be "too light" we would have

$$E_\mu > E_{\text{thresh}}.$$

On the other hand we know the highest observed energies of photons to be

$$E_\gamma = 1\cdot 10^{13}\,\text{eV}.$$

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The transferred energy (to a photon) mentioned results in

$$E_\gamma \geq 2mc^2.$$

These two observations combined put an upper limit (Not "too heavy") on $m$.

*1.3.2. "This assumption of exact physical equivalence makes it impossible for us to speak of the absolute acceleration of the system of reference, ..." (P.17)*

This because any part of the acceleration could be due to a gravitational field.

### 1.4. Local Lorentz Geometry, with and without Coordinates

*1.4.1. Hint: What about breakdown at small scales? (P.21)*

"The geometry of spacetime is locally Lorentzian everywhere."

### 1.5. Time

### 1.6. Curvature

### 1.7. Effect of Matter on Geometry

## 2. FOUNDATIONS OF SPECIAL RELATIVITY

### 2.1. Quantum Mechanics

### 2.2. Symmetries

*2.2.1. "For this to be unitary and linear, t must be Hermitian and linear" (P.51)*

Linearity is trivial and hermiticity follow from the following observation:

$$\begin{aligned}\langle U\Psi|U\Phi\rangle &= \langle(1+i\varepsilon t)\Psi|(1+i\varepsilon t)\Phi\rangle \\ &= \langle\Psi|\Phi\rangle + \varepsilon i\left(\langle\Psi|t\Phi\rangle - \langle t\Psi|\Phi\rangle\right) + \mathcal{O}\left(\varepsilon^2\right) \\ &\overset{Eq.\,(2.2.2)}{\Leftrightarrow} \langle\Psi|t\Phi\rangle = \langle t\Psi|\Phi\rangle \\ &\overset{Eq.\,(2.1.5)}{\Leftrightarrow} t^\dagger = t\end{aligned}$$

*2.2.2. Eq. (2.2.19) (P.54)*

$f^a_{bc}$ and $f^a$ have to be real as $\theta^a$ are real.

## 3. THE ELECTROMAGNETIC FIELD

### 3.1. "In" and "Out" States


## ACKNOWLEDGMENTS

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