Solutions to General Relativity by Wald

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Chapter 2 Solutions

a) Show that the overlap functions f_i[±] ◦ (f_j[±])⁻¹ are C[∞], thus completing the demonstration given in section 2.1 that S² is a manifold.

- b) Show by explicit construction that two coordinate systems (as opposed to the six used in the text) suffice to cover S². (It is impossible to cover S² with a single chart, as follows from the fact that S² is compact, but very open subset of R² is noncompact.)
- a) The maps are defined as acting on the standard embedding of the sphere into ℝ³. f_i[±] is a projection of upper (lower) hemisphere into the plane, for example

$$f_2^{\pm}(x^1, x^2, x^3) = (x^1, x^3),$$

and the others are similar. The inverse map stretches the plane up or down into the corresponding hemisphere,

$$(f_2^{\pm})^{-1}(y^1, y^2) = (y^1, \pm \sqrt{1 - ((y^1)^2 + (y^2)^2)}, y^2),$$

and so on. The overlap map then projects out two of these coordinates, so up to exchanging coordinates it is either of the two maps

$$(y^1, y^2) \longrightarrow (y^1, y^2)$$

 $(y^1, y^2) \longrightarrow (y^i, \pm \sqrt{1 - ((y^1)^2 + (y^2)^2)}).$

both of which are C^{∞} in their domain of definition, $(y^1)^2 + (y^2)^2 < 1$.

b) Construct a chart by drawing a line from the north pole N through any given point p ≠ N on the sphere. The point where this line hits the plane x³ = 0 is the image of p under the chart. This map is defined for all points except N and is called stereographic projection from N. A similar chart defined at S (or any other chart about S) then together with the first form an atlas for S². An explicit form of the map can be found geometrically. The line through p and N (thought of as vector in R³) is (with N = (0, 0, 1))

$$p + t(p - N) = (t(1 + p^1), t(1 + p^2), t(1 + p^3) - t).$$

Solving for when $x^3 = 0$ we get

$$t = \frac{p^3}{1 - p^3}$$
.

which then gives

$$x^i = \frac{p^i}{1-p^3}.$$

The inverse maps are found similarly by starting with a point (y^1, y^2) in the plane, constructing the line N + t(N - y) through N and y and finding where this hits the sphere:

$$1 = |x(t)|^2 = (y^1)^2 t^2 + (y^2)^2 t^2 + (t+1)^2,$$

which has solution

$$t = \frac{-2}{1 + |y|^2}$$

and gives the mapping

$$(y^1,y^2) \mapsto \frac{1}{1+|y|^2}(2y^1,2y^2,|y|^2-1).$$

General Relativity Wald Solutions Manual

Guillaume Favre

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