Solutions to *General Relativity* by Wald

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Chapter 2 Solutions

1. *a) Show that the overlap functions $f_i^\pm \circ (f_j^\pm)^{-1}$ are C^∞, thus completing the demonstration given in section 2.1 that S^2 is a manifold.*

b) Show by explicit construction that two coordinate systems (as opposed to the six used in the text) suffice to cover S^2. (It is impossible to cover S^2 with a single chart, as follows from the fact that S^2 is compact, but very open subset of $\mathbb{R}^2$ is noncompact.)

a) The maps are defined as acting on the standard embedding of the sphere into $\mathbb{R}^3$. $f_i^\pm$ is a projection of upper (lower) hemisphere into the plane, for example

$$f_2^+(x^1, x^2, x^3) = (x^1, x^3),$$

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

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

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

$$\begin{aligned}(y^1, y^2) &\longmapsto (y^1, y^2)\\ (y^1, y^2) &\longmapsto (y^1, \pm\sqrt{1 - ((y^1)^2 + (y^2)^2)}),\end{aligned}$$

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 $p \neq N$ on the sphere. The point where this line hits the plane $x^3 = 0$ 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 S^2. An explicit form of the map can be found geometrically. The line through p and N (thought of as vector in $\mathbb{R}^3$) 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

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

General Relativity Wald Solutions Manual

Robert B. Scott

General Relativity Wald Solutions Manual:

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