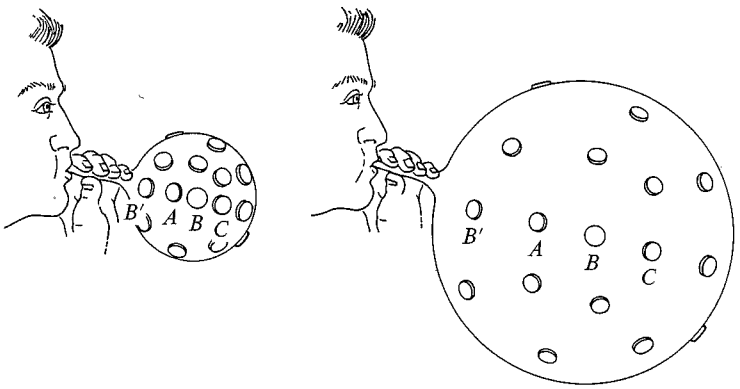

Figure 27.2.
Inflation of a balloon covered with pennies as a model for the expansion of the universe. Each penny A may well consider itself to be the center of the expansion because the distance from A to any neighbor B or C increases the more the more remote that neighbor was to begin with ("the Hubble relation"). The pennies themselves do not expand (constancy of sun-Earth distance, no expansion of a meter stick, no increase of atomic dimensions). The spacing today between galaxy and galaxy ($\sim 10^6$ lyr) is roughly ten times the typical dimension of a galaxy ($\sim 10^5$ lyr).

Notice that the coefficients $\gamma_{ij}(x^k)$ describe the shape not only of the initial hypersurface, but also of all other hypersurfaces of homogeneity. All that changes in the geometry from one hypersurface to the next is the scale of distances. All distances between spatial grid points (fluid world lines) expand by the same factor $a(t)$, leaving the shape of the hypersurface unchanged. This is a consequence of homogeneity and isotropy; and it is precisely true only if the model universe is precisely homogeneous and isotropic.

What expands in the universe, and what does not

Of all the disturbing implications of "the expansion of the universe," none is more upsetting to many a student on first encounter than the nonsense of this idea. The universe expands, the distance between one cluster of galaxies and another cluster expands, the distance between sun and earth expands, the length of a meter stick expands, the atom expands? Then how can it make any sense to speak of any expansion at all? Expansion relative to what? Expansion relative to nonsense! Only later does he realize that the atom does not expand, the meter stick does not expand, the distance between sun and earth does not expand. Only distances between clusters of galaxies and greater distances are subject to the expansion. Only at this gigantic scale of averaging does the notion of homogeneity make sense. Not so at smaller distances. No model more quickly illustrates the actual situation than a rubber balloon with pennies affixed to it, each by a drop of glue. As the balloon is inflated (Figure 27.2) the pennies increase their separation one from another but not a single one of them expands! [For mathematical detail see, e.g., Noerdlinger and Petrosian (1971).]

GRAVITATION

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