

Solutions to Problems in Goldstein,
Classical Mechanics, Second Edition

Homer Reid

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Chapter 3

Problem 3.1

A particle of mass m is constrained to move under gravity without friction on the inside of a paraboloid of revolution whose axis is vertical. Find the one-dimensional problem equivalent to its motion. What is the condition on the particle's initial velocity to produce circular motion? Find the period of small oscillations about this circular motion.

We'll take the paraboloid to be defined by the equation $z = \alpha r^2$. The kinetic and potential energies of the particle are

$$\begin{aligned} T &= \frac{m}{2}(\dot{r}^2 + r^2\dot{\theta}^2 + \dot{z}^2) \\ &= \frac{m}{2}(\dot{r}^2 + r^2\dot{\theta}^2 + 4\alpha^2 r^2\dot{r}^2) \\ V &= mgr = m\alpha r^2. \end{aligned}$$

Hence the Lagrangian is

$$L = \frac{m}{2}[(1 + 4\alpha^2 r^2)\dot{r}^2 + r^2\dot{\theta}^2] - m\alpha r^2.$$

This is cyclic in θ , so the angular momentum is conserved:

$$l = mr^2\dot{\theta} = \text{constant}.$$

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