

Classical Mechanics Problem 1: Central Potential
Solution

a) Integrals of motion for a central potential $V(r)$:

$$\begin{aligned} \text{Angular Momentum} \quad L &= r v_\phi = r^2 \dot{\phi} \\ \text{Energy per unit mass} \quad E &= \frac{1}{2} (\dot{r}^2 + v_\phi^2) + V(r) = \frac{1}{2} \dot{r}^2 + V_{\text{eff}}(r) \end{aligned}$$

where v_ϕ is the tangential velocity and V_{eff} is defined as

$$V_{\text{eff}}(r) = V(r) + \frac{L^2}{2r^2}$$

If the orbit is circular, the distance of the test body from the origin is invariant: $\dot{r} = 0$, which implies that the body is always at the equilibrium-distance:

$$\frac{dV_{\text{eff}}}{dr} = 0 \quad \Rightarrow \quad \frac{dV}{dr} = \frac{L^2}{r^3} = \frac{v_\phi^2}{r} = r \dot{\phi}^2$$

then

$$\dot{\phi} = \omega_\phi = \frac{L}{r^2} = \left(\frac{1}{r} \frac{dV}{dr} \right)^{1/2}$$

so for the period we get

$$\boxed{T_\phi = \frac{2\pi}{\omega_\phi} = 2\pi \left(\frac{1}{r} \frac{dV}{dr} \right)^{-1/2}}$$

b) Write the orbit as in the statement of the problem:

$$r(t) = r_0 + \epsilon(t) \quad \text{with} \quad \frac{dV_{\text{eff}}}{dr}(r_0) = 0 \quad \text{and} \quad \epsilon^2 \ll r_0^2.$$

The energy per unit mass is now $E = \frac{1}{2} \dot{\epsilon}^2 + V_{\text{eff}}(r_0 + \epsilon)$, and since ϵ is small we may Taylor-expand the potential as

$$V_{\text{eff}}(r_0 + \epsilon) = V_{\text{eff}}(r_0) + \underbrace{\frac{dV_{\text{eff}}}{dr}(r_0)}_{=0} \epsilon + \frac{1}{2} \frac{d^2 V_{\text{eff}}}{dr^2}(r_0) \epsilon^2 + \mathcal{O}(\epsilon^3)$$

so then

$$E - V_{\text{eff}}(r_0) = \frac{1}{2} \dot{\epsilon}^2 + \frac{1}{2} \frac{d^2 V_{\text{eff}}}{dr^2}(r_0) \epsilon^2 + \mathcal{O}(\epsilon^3) = \text{const.}$$

In the above equation we readily recognize the equation of the simple harmonic oscillator with

$$\boxed{\omega_\epsilon = \left(\frac{d^2 V_{\text{eff}}}{dr^2} \right)_{r=r_0}^{1/2}}$$

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Foundations of Quantum Physics Charles E. Burkhardt, Jacob J. Leventhal, 2008-12-15 This book is meant to be a text for a first course in quantum physics It is assumed that the student has had courses in Modern Physics and in mathematics through differential equations The book is otherwise self contained and does not rely on outside resources such as the internet to supplement the material SI units are used throughout except for those topics for which atomic units are especially convenient It is our belief that for a physics major a quantum physics textbook should be more than a one or two semester acquaintance Consequently this book contains material that while germane to the subject the instructor might choose to omit because of time limitations There are topics and examples included that are not normally covered in introductory textbooks These topics are not necessarily too advanced they are simply not usually covered We have not however presumed to tell the instructor which topics must be included and which may be omitted It is our intention that omitted subjects are available for future reference in a book that is already familiar to its owner In short it is our hope that the student will use the book as a reference after having completed the course We have included at the end of most chapters a Retrospective of the chapter This is not meant to be merely a summary but rather an overview of the importance of the material and its place in the context of previous and forthcoming chapters Soviet Physics, JETP., 1983 Quantum States of Atoms, Molecules, and Solids Michael A. Morrison, Thomas Leo Estle, Neal F. Lane, 1976 Problems after each chapter **Nuclear Science Abstracts**, 1972-04 Exact Nonlinear Inversion of Electromagnetic Induction Soundings Giovanni B. Marchisio, 1985

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