

# Corrections to Classical Mechanics with MATLAB applications

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Jones and Bartlett Publishers, Sudbury MA, 2009

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The equations and text on the pages listed below are written in the way they should have appeared in the original text.

## Page 5

$$\vec{a}_j = \vec{f}_{ji} / m_j = -\vec{f}_{ij} / m_j. \quad (1.2.3c)$$

## Pages 39-40

$$v = \left( \frac{mg}{C} + v_0 \right) e^{-\frac{C}{m}t} - \frac{mg}{C}. \quad (2.5.9)$$

...

$$y(t) = y_0 - \left[ \frac{m}{C} \left( \frac{mg}{C} + v_0 \right) e^{-\frac{C}{m}t} + \frac{mg}{C} t \right]_0^t,$$

or

$$y(t) = y_0 - \frac{mg}{C} t - \frac{m}{C} \left( \frac{mg}{C} + v_0 \right) \left( e^{-\frac{C}{m}t} - 1 \right). \quad (2.5.10)$$

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formulas (2.5.6, 9, 10). In order to find the time the body reaches the ground,  $t_{\max}$ , we solve the equation

$$0 = y_0 - \frac{mg}{C} t_{\max} - \frac{m}{C} \left( \frac{mg}{C} + v_0 \right) \left( e^{-\frac{C}{m}t_{\max}} - 1 \right)$$
 numerically within the script using the MATLAB provided

function fzero. The solution process requires an initial guess for  $t_{\max}$ . This is obtained by choosing the positive

root in the equation for the position without air resistance; i.e.,  $0 = y_0 + v_0 t_{\text{guess}} - \frac{g}{2} t_{\text{guess}}^2$ . This yields

$$t_{\text{guess}} = \frac{v_0}{g} + \sqrt{\left( \frac{v_0}{g} \right)^2 + \frac{2y_0}{g}}.$$

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satisfied. First, using the last of (3.2.7a), we notice that the velocity is given by

$$v = \frac{dx}{dt} = C\omega \cos(\omega t + \delta), \quad (3.2.8)$$

and that the acceleration is  $a = dv/dt = -C\omega^2 \sin(\omega t + \delta) = -\omega^2 x$ , as expected for harmonic motion. If at  $t = 0$ , the spring is displaced by amount  $x_0$ , with speed  $v_0$ , then (3.2.8) and the last of (3.2.7a) can be used to write

$$x_0 = C \sin \delta, \quad v_0 = C\omega \cos \delta, \quad (3.2.9)$$

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of  $x_b$  into (3.3.4), the approximate frequency of vibration is found to be  $\omega = \sqrt{\frac{32B^5}{81mA^4}} = \sqrt{\frac{32u_0}{81ma_0^2}}$ .

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which means that the molecular ionization energy is  $(4/27)u_0$  in our units. The related molecular ...

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underdamped solution equations where the parameters used are  $m = 1\text{kg}$ ,  $k = 1\text{N/m}$ ,  $c = 0.08\text{N}\cdot\text{s/m}$ ,  $x_0 = 1.0\text{m}$ , and  $v_0 = 5.0\text{m/s}$ .

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The figure 3.12 contains the forced solution as well as the full solution. The full solution is sum of the homogeneous (equation 3.4.11) and the inhomogeneous (equation 3.4.22); i.e.,  $x = x_{\text{homogeneous}} + x_{\text{forced}}$  has been plotted for each set of parameters under the plot of each forced solution.

### Pages 77-78

The equation of motion for the damped pendulum is similar to (4.2.4) with a term involving the frictional effects. If we assume the resistive term is proportional to the angular speed, then we have

$$\frac{d^2\theta}{dt^2} + \frac{c}{m} \frac{d\theta}{dt} + \frac{g}{\ell} \theta = 0, \quad (4.2.6a)$$

where  $c$  is the coefficient due to friction. This equation can be written as

$$\frac{d^2\theta}{dt^2} + 2\gamma \frac{d\theta}{dt} + \omega_0^2 \theta = 0, \quad (4.2.6b)$$

where  $\gamma = c/2m$ ,  $\omega_0 = \sqrt{g/\ell}$ . This equation is similar to the damped harmonic oscillator problem of Chapter 3.

Thus, the underdamped solution we seek is from Section 3.4,

$$\theta(t) = \theta_0 e^{-\gamma t} \cos \omega t, \quad (4.2.7)$$

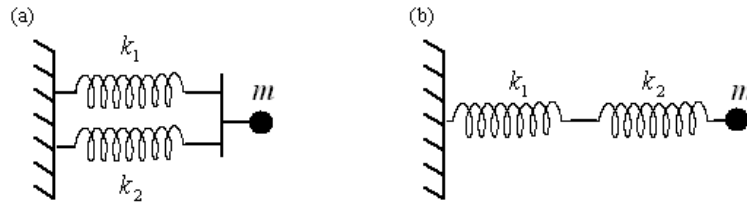
so that at  $t = 0$ ,  $\theta(0) = \theta_0$  and where

$$\omega = \sqrt{\omega_0^2 - \gamma^2}. \quad (4.2.8)$$

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When springs are organized in a parallel configuration as shown in figure 4.11a or in a series arrangement as in figure 4.11b, the springs act as a single spring with an effective spring constant.

Figure 4.11  
 a) Springs in parallel  
 b) Springs in series



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$$\omega = \omega_0 \sqrt{1 - 3a_3 \left( \frac{A_1}{2\omega_0} \right)^2} \rightarrow \omega_0 \sqrt{1 - \frac{A_1^2}{8}}, \quad (4.15.3b)$$

or for the period

$$\tau_{nl} = \tau_0 / \sqrt{1 - (A_1^2 / 8)}, \quad (4.15.3c)$$

where the subscript *nl* indicates the *non-linear* approximation. This shows that the period is actually longer by a factor of  $1 / \sqrt{1 - (A_1^2 / 8)}$  compared to the simple pendulum. Thus, according to (4.15.3a, c) the period of the pendulum depends on the initial amplitude  $\theta_0$  in radians. If the amplitude is small, then  $\tau_0$  is a good approximation for the period. It is useful to compare  $\tau$  versus  $\theta_0$  obtained this way to that obtained from the full numerical solution. However, equation (4.15.1) can be conveniently solved numerically to obtain  $\theta(t)$  but not  $\tau(\theta)$ . Thus, rather than using (4.15.1), it is best to look at the energy equation

$$E = mg \ell (1 - \cos \theta_0) = \frac{1}{2} I \omega^2 + mg \ell (1 - \cos \theta), \quad (4.15.4)$$

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Example 5.1

After traveling for 5 km at an angle between zero and ninety degrees with respect to a certain road that points east, a motorcycle rider runs out of gas. The rider is able to walk in a straight line back towards the road, and perpendicular to it, for a distance of 4 km. a) How far is the rider from the initial starting position. b) What was the initial direction of travel with respect to the road? c) Write a unit vector corresponding to this direction.

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Consider points  $P_1$  and  $P_2$  located at positions  $\vec{r}_1$ , and  $\vec{r}_2$  from the origin respectively as shown in figures 5.11a,b.

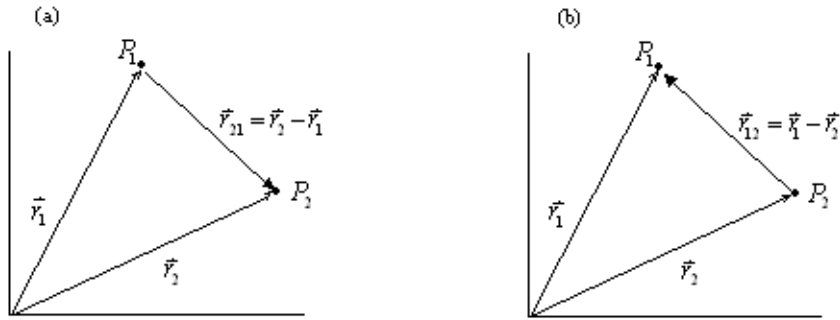


Figure 5.11 Relative displacement of a)  $P_2$  with respect to  $P_1$ , b)  $P_1$  with respect to  $P_2$

The relative displacement of  $P_2$  with respect to  $P_1$  is given by

$$\vec{r}_{21} = \vec{r}_2 - \vec{r}_1, \quad (5.5.5a)$$

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```

=====
%gradient_ex.m
%This script plots and evaluates the function f=x*exp(-(x^2+y^2+z^2)) and its gradient
%The plots are done versus x,y at a certain z value
warning off; %suppress unwanted warnings by plotter if needed
clear;
vmax=2.0;
xmax=vmax; ymax=vmax; zmax=vmax; % x,y,z limits
vs=0.1;
xs=vs; ys=vs; zs=vs; % step size
N=2*vmax/vs; % number of points to be plotted is NxNxN
dv=0.1;
dx=dv; dy=dv; dz=dv; % used in the gradient
m=round(N/2+5); zm=-zmax+(m-1)*zs; % value of z at which we plot f(x,y,z)
[x,y,z]=meshgrid(-xmax:xs:xmax,-ymax:ys:ymax,-zmax:zs:zmax);
f=x.*exp(-(x.^2+y.^2+z.^2)); % the desired function
[dfx,dfy,dfz] = gradient(f,dx,dy,dz);%gradient of f(x,y,z)
%mesh(x(:,:,m),y(:,:,m),f(:,:,m)) % can do a mesh if desired
surf(x(:,:,m),y(:,:,m),f(:,:,m)) % surface plot
xlabel('x','FontSize',14)
ylabel('y','FontSize',14)
zlabel('f(x,y,z)','FontSize',14)
str=cat(2,'f(x,y,z)=x*exp(-x^2-y^2-z^2) at ','z=',num2str(zm,3));
title(str,'FontSize',14)
figure
%contour(x(:,:,m),y(:,:,m),f(:,:,m),20)%contour plot 20 line case
[C,h] = contour(x(:,:,m),y(:,:,m),f(:,:,m));% generate contour plot
clabel(C,h,'FontSize',12)% add countour labels
hold on
quiver(x(:,:,m),y(:,:,m),dfx(:,:,m),dfy(:,:,m))%draw the gradient as arrows at x
xlabel('x','FontSize',14)
ylabel('y','FontSize',14)
str=cat(2,'f(x,y,z)=x*exp(-x^2-y^2-z^2) at ','z=',num2str(zm,3));
title(str,'FontSize',14)
=====

```

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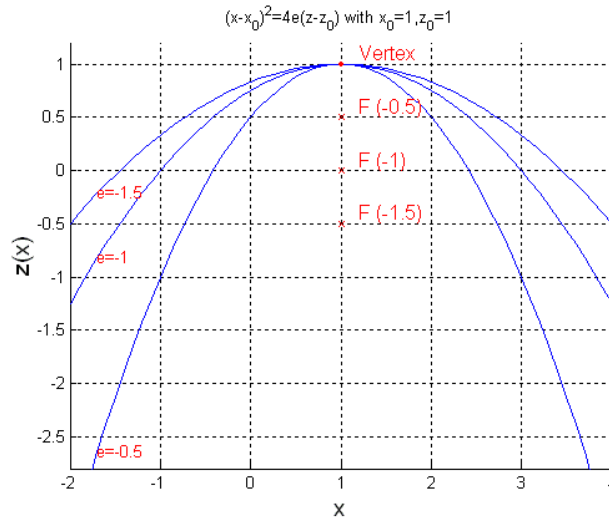
These equations can be written in a vector notation as

$$\begin{aligned} \vec{r} &= \vec{r}_i + \vec{v}_i t - \frac{1}{2} g t^2 \hat{k}, & \vec{v} &= \vec{v}_i - g t \hat{k}, \\ \vec{r}_i &= x_i \hat{i} + z_i \hat{k}, & \vec{v}_i &= v_{ix} \hat{i} + v_{iz} \hat{k}. \end{aligned} \tag{6.2.3}$$

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 where  $e$  is the parabola focus distance. The parabola is concave down (up) if  $e < 0$  ( $e > 0$ ). Figure 6.2 shows a series of parabolas for  $e < 0$ . The lower values of  $e$  have higher curvatures.

Figure 6.2  
 Parabolas of different focal points ( $e$ ).



The focal points corresponding to each  $e$  are shown to move farther away as the curvature decreases.

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Table 6.1 Projectile Motion Symmetry between the angle and its complement		
Test launching Angle: $\theta$	Complement: $\pi/2 - \theta$	$\sin 2\theta = \cos(\theta) \cos(\pi/2 - \theta)$
(1) 0	$\pi/2$	$\cos(0) \cos(\pi/2) = 0$
(2) $\pi/12 = \pi/2 - 5\pi/12$	$5\pi/12$	$\cos(\pi/12) \cos(5\pi/12) = 0.25$
(3) $\pi/6 = \pi/2 - \pi/3$	$\pi/3$	$\cos(\pi/6) \cos(\pi/3) = 0.433$
(4) $\pi/4 = \pi/2 - \pi/4$	$\pi/4$	$\cos(\pi/4) \cos(\pi/4) = 0.5$
(5) $\pi/3 = \pi/2 - \pi/6$	$\pi/6$	$\cos(\pi/3) \cos(\pi/6) = 0.433$
(6) $5\pi/12 = \pi/2 - \pi/12$	$\pi/12$	$\cos(5\pi/12) \cos(\pi/12) = 0.25$
(7) $\pi/2$	0	$\cos(\pi/2) \cos(0) = 0$

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$$z(t) = 0 = \left[ -\frac{mg}{C}t - \frac{m}{C} \left( \frac{mg}{C} + v_{iz} \right) \left( e^{\frac{C}{m}t} - 1 \right) \right]_{t=t_{\max}}, \quad (6.2.15)$$

...

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To obtain an approximate result for  $x_{\max}$  in (6.2.17), we can expand the exponential term to first order in  $C$  and simplifying to get  $x_{\max} \sim v_{ix} t_{\max}$ . Finally, substituting (6.2.18) into this we find

$$x_{\max} \sim \frac{2v_{ix}v_{iz}}{g} - \frac{2Cv_{ix}v_{iz}^2}{mg^2}, \quad (6.2.19)$$

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While there are an infinite number of paths to choose from to go from point  $o$  to point  $P$ , only three are shown in the illustration. Each of the paths 1 and 2 has sub-paths labeled 1a, 1b and 2a, 2b respectively. If we choose path 1, the line integral (6.3.2) is written as

$$\begin{aligned} V_1 &= - \int_{\substack{\text{path 1a,} \\ x=0, dx=0}} \vec{F} \cdot d\vec{r} - \int_{\substack{\text{path 1b,} \\ y=\ell, dy=0}} \vec{F} \cdot d\vec{r} \\ &= -A_0 \int_{x=0, y=0}^{x=0, y=\ell} 0 \hat{i} \cdot \hat{j} dy - A_0 \int_{x=0, y=\ell}^{x=\ell, y=\ell} x \hat{i} \cdot \hat{i} dx = -A_0 \frac{x^2}{2} \Big|_{x=0}^{x=\ell} = -A_0 \frac{\ell^2}{2}, \end{aligned} \quad (6.3.3)$$

...

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$$\begin{aligned} V_2 &= - \int_{\substack{\text{path 2a,} \\ y=0, dy=0}} \vec{F} \cdot d\vec{r} - \int_{\substack{\text{path 2b,} \\ x=\ell, dx=0}} \vec{F} \cdot d\vec{r} \\ &= - \int_{x=0, y=0}^{x=\ell, y=0} (0) \cdot \hat{i} dx - \int_{x=\ell, y=0}^{x=\ell, y=\ell} (Axy \hat{i} + By \hat{j}) \cdot \hat{j} dy = - \frac{By^2}{2} \Big|_{y=0}^{y=\ell} = - \frac{B\ell^2}{2}, \end{aligned} \quad (6.3.7)$$

...

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Integrating once more with respect to time we get

$$r = \int \dot{r} dt = A_1 \int e^{-\frac{qB_0}{m}t} dt = A_2 e^{-\frac{qB_0}{m}t} + A_3, \quad (6.4.11)$$

where we have defined  $A_2 \equiv -mA_1/iqB_0$ . Since  $A_2$  and  $A_3$  are as yet unknown, for convenience we let them take the forms  $A_2 = ce^{-i\varphi}$ ,  $A_3 = a + ib$ , where  $\varphi$ ,  $a$ ,  $b$ , and  $c$  are constants that depend on the initial conditions. With these definitions and the use of Euler's formula  $e^{i\theta} = \cos(\theta) + i\sin(\theta)$ , we obtain from (6.4.11)

$$r = c \left[ \cos\left(\frac{qB_0}{m}t + \varphi\right) - i \sin\left(\frac{qB_0}{m}t + \varphi\right) \right] + a + ib, \quad (6.4.12)$$

from which, by separating the real and imaginary parts, we find

$$x(t) = \text{Re}(r) = c \cos(\omega_c t + \varphi) + a, \quad y(t) = \text{Im}(r) = -c \sin(\omega_c t + \varphi) + b, \quad (6.4.13)$$

where we have used the cyclotron frequency  $\omega_c \equiv qB_0/m$  or period  $\tau = 2\pi/\omega_c = 2\pi m/(qB_0)$ . The frequency of the particle's oscillation turns out to be independent of the particle's speed. Two more aspects of this result are worth noting. One is that (6.4.13) can be written as

$$(x-a)^2 + (y-b)^2 = c^2, \quad (6.4.14)$$

which indicates that the motion is a circle of radius  $R = c$  centered at  $(x = a, y = b)$ . Another is that, from (6.4.13), we can obtain the radius of the circle as follows,

$$\dot{x}^2 + \dot{y}^2 = R^2 \omega_c^2 = v^2 \Rightarrow R = v/\omega_c = mv/qB_0. \quad (6.4.15)$$

If in the last of (6.4.15) we multiply both sides by  $v$  and rearrange the result, this also means that the particle, while performing circular motion, is subject to a centripetal force  $mv^2/R = qvB_0$ , whose source is the magnetic field and whose direction is toward the center of the circle as shown in figure 6.10.

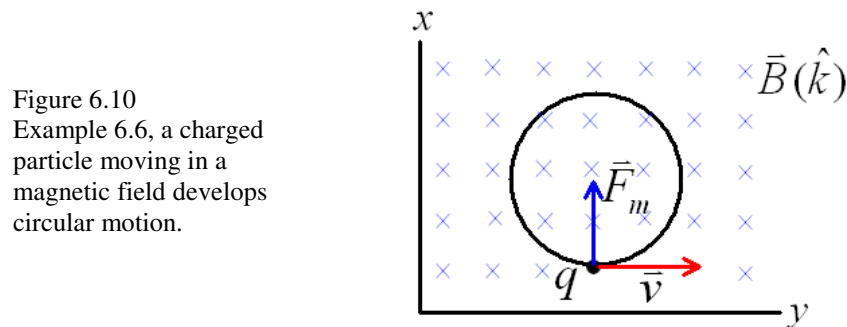


Figure 6.10  
Example 6.6, a charged particle moving in a magnetic field develops circular motion.

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6.15) In an experiment similar to that performed by J. J. Thomson in 1897, electrons are emitted from a hot filament and travel through a region where they are accelerated by an applied potential  $V$  as shown in figure 6.15. Once they leave the accelerating region at a speed  $v_0$ , the electrons enter a parallel plate capacitor of length  $L$  where a constant field  $E$  deflects them by an amount  $y$ . a) What is the speed  $v_0$  of the electrons? b) Obtain an expression for the deflection  $y$  in terms

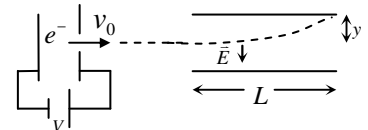


Figure 6.15

of  $v_0$ ,  $E$ ,  $L$ , and  $m_e$ . c) If we wished to ensure the electrons are not deflected within the capacitor, we can add a constant magnetic field there. Obtain an expression for the magnitude of this magnetic field in terms of  $v_0$  and  $E$ . In what direction should the magnetic field be oriented?

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The polar acceleration is

$$\bar{a} = \frac{d\bar{v}}{dt} = \ddot{\bar{r}} = \frac{d}{dt}(\dot{r}\hat{r} + r\dot{\theta}\hat{\theta}) = \ddot{r}\hat{r} + \dot{r}\frac{d\hat{r}}{dt} + \dot{r}\dot{\theta}\hat{\theta} + r\ddot{\theta}\hat{\theta} + r\dot{\theta}\frac{d\hat{\theta}}{dt}. \quad (7.2.9)$$

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for the minimum radius and the eccentricity of the orbit have been made. The eccentricity is a quantity that is associated with an ellipse. In the range of  $0 \leq e \leq 1$ , the shape described by (8.6.8) can go from a circle ( $e = 0$ ) to a parabola ( $e = 1$ ), with an ellipse in between ( $0 < e < 1$ ).

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where, for an attractive force ( $K < 0$ ), the positive (negative) root gives the larger (smaller) value of  $1/r_m$ .

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From figure 8.8b, we can write  $\bar{r} = r\hat{r}$ , and  $d\bar{r} = dr\hat{r} + r d\theta\hat{\theta}$ , in polar coordinates, and since the area of the triangle shown is formally given by  $dA = |\bar{r} \times d\bar{r}|/2$ , then ...

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`%kepler3rd.m - This script is designed to look at the solar system planets`

```
...
h=legend('Planets','Comparison',' Fit',4); set(h,'FontSize',12)
str1=cat(2,' Line Fit=',num2str(c(1),4),'*x + ',num2str(c(2),4));
str2=cat(2,' r^2=',num2str(rr,10));
text(x(6),y(9)*(1+0.05),str1,'FontSize',9);%post fit
text(x(6),y(9),str2,'FontSize',9);
%---- tau = a^{3/2} figure
xth=[0:0.1:max(a)]; %variable for pth
```

...

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$$\omega = \sqrt{\frac{k_{\text{eff}}}{m}}, \quad (8.9.1),$$

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$$V_{\text{eff}}''(r) = -F'(r_c) - 3\frac{F(r_c)}{r_c}. \quad (8.9.4)$$

Therefore, the oscillations about a circle will have associated with them the  $r_{\min}$  and the  $r_{\max}$  radii with frequency,  $\omega = \sqrt{(-F'(r_c) - 3F(r_c)/r_c)/m}$ , or period

$$\tau = \frac{2\pi}{\omega} = 2\pi \sqrt{\frac{m}{-F'(r_c) - 3\frac{F(r_c)}{r_c}}}. \quad (8.9.5)$$

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$$\frac{kq_e^2 \tau^2}{m_\alpha a_b^3} \equiv 1 \Rightarrow \tau = \sqrt{\frac{m_\alpha a_b^3}{kq_e^2}} = \sqrt{\frac{4(1.66 \times 10^{-27} \text{ kg})(10^{-15} \text{ m})^3}{(9 \times 10^9 \frac{\text{Nm}^2}{\text{C}^2})(1.602 \times 10^{-19} \text{ C})^2}} = 1.695 \times 10^{-22} \text{ s}. \quad (10.3.3)$$

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...

movie(M,1,15)      %play once, at 15 frames per second

...

### Page 531

$$7. -\ell^2 (1 + 2\ell/3)/2.$$

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$$\begin{aligned} \nabla^2 f &= \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2} + \frac{\partial^2 f}{\partial z^2} && \text{Cartesian} \\ &= \frac{1}{\rho} \frac{\partial}{\partial \rho} \rho \frac{\partial f}{\partial \rho} + \frac{1}{\rho^2} \frac{\partial^2 f}{\partial \varphi^2} + \frac{\partial^2 f}{\partial z^2} && \text{Cylindrical} \\ &= \frac{1}{r^2} \frac{\partial(r^2 f)}{\partial r} + \frac{1}{r^2 \sin \theta} \frac{\partial}{\partial \theta} \left( \sin \theta \frac{\partial f}{\partial \theta} \right) + \frac{1}{r^2 \sin^2 \theta} \frac{\partial^2 f}{\partial \varphi^2} && \text{Spherical} \end{aligned}$$

Email me if you see any more errors. Thank you,

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