Answers and Hints to Exercise Questions in "Solar System Dynamics"
(Last Updated: 16 January 2021)

Chapter 2

Q2.1 Many of the techniques of Sects. 2.2 and 2.3 are still applicable with minor modifications. Once you get the modified version of Eq. (2.13) you could just show that the polar equation of a centred ellipse satisfies the equation.

Q2.2 Using the semi-major axes the time interval between conjunctions is 2.135 years. Given that $e_{\rm M} \gg e_{\rm E}$ calculate the separation for conjunctions at Mars' perihelion and aphelion. The ratio should be 1.75 and so the minimum distance varies by a factor ~ 2. A "very close" opposition of Mars occurs when Mars is at perihelion. Imagine Earth and Mars in this configuration with the Sun, Earth and Mars defining the reference line. Now think what the geometry will be at the next conjunction, 2.135 years later. This gives the interval between close approaches as 15.8 years. In order to see what is happening plot the *separation* of Mars and Earth as a function of time for the years 1985–2002 using the data from Table A.2. The minimum separation at the closest opposition is 0.392 AU on 22 September 1988. The minimum separation at the furtherest opposition is 0.674 AU on 12 February 1995. The next close opposition occurred on 27 August 2003.

Q2.3 For a hyperbolic orbit $a < 0$ and $e > 1$ but Eq.(2.20) still holds and the pericentre distance is still $a(1-e)$. Using data from Tables A.4 and A.9 the maximum deflections are (i) 142.4° for Jupiter and (ii) 14.06° for Titan.

Q2.4 To show why $\mathbf{e}$ has to lie in the orbital plane consider the directions of the vectors $\mathbf{r}$, $\mathbf{v}$, $\mathbf{h}$ and $\mathbf{h} \times \mathbf{v}$. To show that $\mathbf{e}$ is a constant you need to show that $\dot{\mathbf{e}} = 0$.

Q2.5 $E = 132.14°$, $f = 158.47°$, $r = 4.5892$ AU, $\theta = 240.67°$. You can see the images taken by the *Galileo* spacecraft at `https://solarsystem.nasa.gov/resources/2466/comet-shoemaker-levy-9-fragment-w-impacts-jupiter-1994/?category=missions_galileo`

Q2.6 At noon on 14 August 2126 the Earth has position vector $\mathbf{r}_{\rm E} = (0.773762, -0.654228, 0)$ AU while Swift-Tuttle has position vector $\mathbf{r}_{\rm ST} = (-4.48642, 4.73128, 1.56172)$ AU. Hence the separation is 7.68844 AU. In fact, the minimum separation is as low as 1.238 AU in mid-2128 but still nothing to worry about. However, it should be noted that these answers are based on a number of assumptions.