# MECH230 - Fall 2024
# Recommended Problems - Set 09

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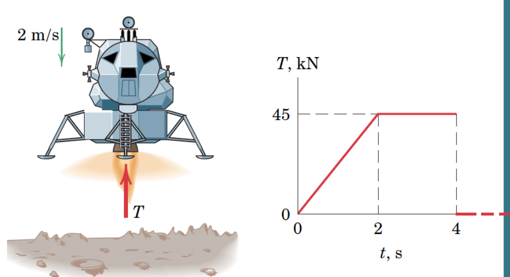
October 9, 2024

The problems are taken from J. L. Meriam, L. G. Kraige, and J. N. Bolton (MKB), Engineering Mechanics: Dynamics, Ninth Edition, Wiley, New York, 2018.

1. [MKB 03-149] This problem is a straightforward application of the Linear Impulse - Linear Momentum equation.

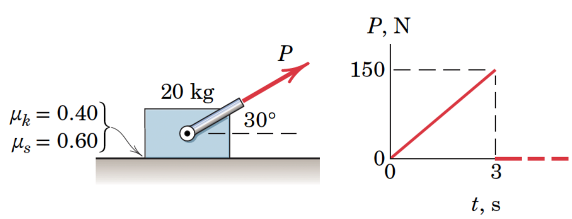
**3/149** The 15 200-kg lunar lander is descending onto the moon's surface with a velocity of 2 m/s when its retro-engine is fired. If the engine produces a thrust $T$ for 4 s which varies with time as shown and then cuts off, calculate the velocity of the lander when $t = 5$ s, assuming that it has not yet landed. Gravitational acceleration at the moon's surface is 1.62 m/s$^2$.




**PROBLEM 3/149**

2. [MKB 03-159] All you need to know from the previous problem is that the block is is subjected to the time-varying horizontal force whose magnitude P is shown in the plot. Note that the force is zero for all times greater than 3 s.

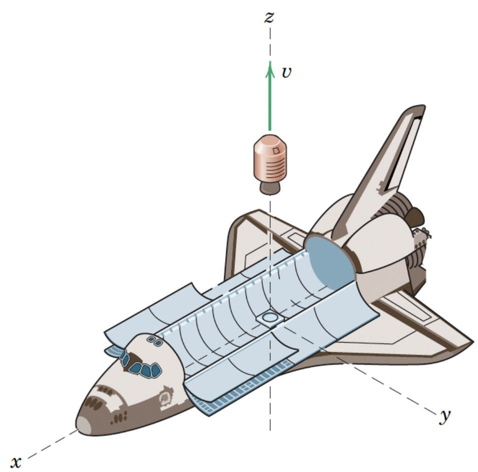
**3/159** All elements of the previous problem remain unchanged, except that the force $P$ is now held at a constant 30° angle relative to the horizontal. Determine the time $t_s$ at which the initially stationary 20-kg block comes to rest.




**PROBLEM 3/159**

3. [MKB 03-161] You are going to use Newton's third law in this problem.

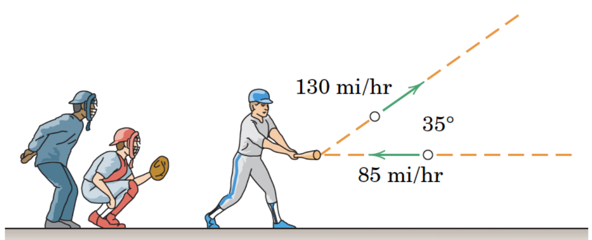
**3/161** The space shuttle launches an 800-kg satellite by ejecting it from the cargo bay as shown. The ejection mechanism is activated and is in contact with the satellite for 4 s to give it a velocity of 0.3 m/s in the $z$-direction relative to the shuttle. The mass of the shuttle is 90 Mg. Determine the component of velocity $v_f$ of the shuttle in the minus $z$-direction resulting from the ejection. Also find the time average $F_{av}$ of the ejection force.




PROBLEM 3/161

4. [03-167]

**3/167** The baseball is traveling with a horizontal velocity of 85 mi/hr just before impact with the bat. Just after the impact, the velocity of the $5\frac{1}{8}$-oz ball is 130 mi/hr directed at 35° to the horizontal as shown. Determine the $x$- and $y$-components of the average force **R** exerted by the bat on the baseball during the 0.005-sec impact. Comment on the treatment of the weight of the baseball ($a$) during the impact and ($b$) over the first few seconds after impact.

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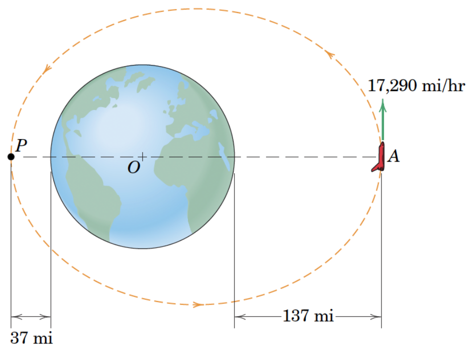
5. [03-177] This is a quintessential central force problem. What quantities of this system are conserved? Refer to table D2 at the end of this document for the radius of the earth.

**3/177** Just after launch from the earth, the space-shuttle orbiter is in the 37 × 137–mi orbit shown. At the apogee point $A$, its speed is 17,290 mi/hr. If nothing were done to modify the orbit, what would be its speed at the perigee $P$? Neglect aerodynamic drag. (Note that the normal practice is to add speed at $A$, which raises the perigee altitude to a value that is well above the bulk of the atmosphere.)



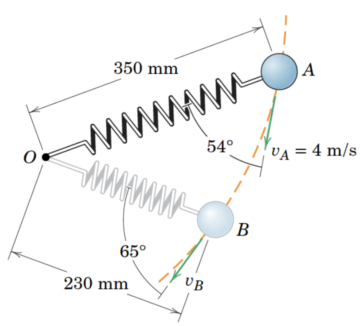

PROBLEM 3/177

6. [03-181]

**3/181** A particle with a mass of 4 kg has a position vector in meters given by $\mathbf{r} = 3t^2\mathbf{i} - 2t\mathbf{j} - 3t\mathbf{k}$, where $t$ is the time in seconds. For $t = 3$ s determine the magnitude of the angular momentum of the particle and the magnitude of the moment of all forces on the particle, both about the origin of coordinates.

7. [03-185]

**3/185** A particle of mass $m$ moves with negligible friction on a horizontal surface and is connected to a light spring fastened at $O$. At position $A$ the particle has the velocity $v_A = 4$ m/s. Determine the velocity $v_B$ of the particle as it passes position $B$.

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8. [03-192] To avoid confusion let's label $r$ in the figure $R$ and the angle $\theta$ requested in the solution as $\beta$.

Step 1. Choose the origin O to be at the bottom of the funnel and setup the cylinderical-polar coordinate system. Derive $\mathbf{v}$ but not $\mathbf{a}$, we will not need it as we will solve the problem by exploiting conservations. The particle is constrained to move on a surface of revolution given by

$$z^2 + (r - 1.15R^2) = R^2 \tag{1}$$

A time derivative of this expression yields

$$z\dot{z} + \dot{r}\left(r - 1.15R^2\right) = 0. \tag{2}$$

Step 2. Draw a free-body diagram of the particle. Express the normal force as $\mathbf{N} = N\mathbf{n}$, where $\mathbf{n}$ is a unit direction normal to the surface of revolution. In theory, $\mathbf{n}$ could be computed from a gradient of (1), but you don't need to do that here. You only need to note that $\mathbf{N}$ has $\mathbf{e}_r$ and $\mathbf{E}_z$ components.

Step 3. In Step III, prove a conservation on the total mechanical energy $E$ and a conservation of $\mathbf{E}_z$ components of the angular momentum $\mathbf{H}^O$. You will need to refer to your FBD to identify these conserved quantities.

Step 4. Calculate the numerical values of $E$ and and $\mathbf{H}_O \cdot \mathbf{E}_x$ using the initial conditions and complete your analysis.

**3/192** A particle is launched with a horizontal velocity $v_0 = 0.55$ m/s from the 30° position shown and then slides without friction along the funnel-like surface. Determine the angle $\theta$ which its velocity vector makes with the horizontal as the particle passes level $O$-$O$. The value of $r$ is 0.9 m.

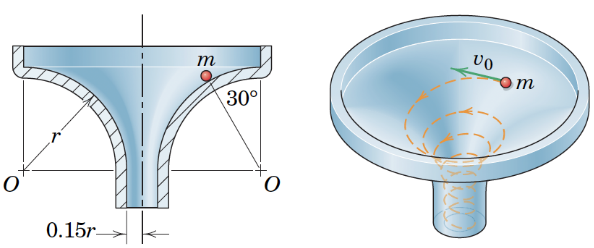


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**TABLE D/2 Solar System Constants**

| | |
|---|---|
| Universal gravitational constant | $G = 6.673(10^{-11})\ \text{m}^3/(\text{kg}\cdot\text{s}^2)$ |
| | $= 3.439(10^{-8})\ \text{ft}^4/(\text{lb-sec}^4)$ |
| Mass of Earth | $m_e = 5.976(10^{24})\ \text{kg}$ |
| | $= 4.095(10^{23})\ \text{lb-sec}^2/\text{ft}$ |
| Period of Earth's rotation (1 sidereal day) | = 23 h 56 min 4 s |
| | = 23.9344 h |
| Angular velocity of Earth | $\omega = 0.7292(10^{-4})\ \text{rad/s}$ |
| Mean angular velocity of Earth–Sun line | $\omega' = 0.1991(10^{-6})\ \text{rad/s}$ |
| Mean velocity of Earth's center about Sun | = 107 200 km/h |
| | = 66,610 mi/hr |

| Body | Mean Distance to Sun km (mi) | Eccentricity of Orbit $e$ | Period of Orbit solar days | Mean Diameter km (mi) | Mass Relative to Earth | Surface Gravitational Acceleration $\text{m/s}^2$ ($\text{ft/sec}^2$) | Escape Velocity km/s (mi/sec) |
|---|---|---|---|---|---|---|---|
| Sun | — | — | — | 1 392 000 (865 000) | 333 000 | 274 (898) | 616 (383) |
| Moon | 384 398[1] (238 854)[1] | 0.055 | 27.32 | 3 476 (2 160) | 0.0123 | 1.62 (5.32) | 2.37 (1.47) |
| Mercury | $57.3 \times 10^6$ ($35.6 \times 10^6$) | 0.206 | 87.97 | 5 000 (3 100) | 0.054 | 3.47 (11.4) | 4.17 (2.59) |
| Venus | $108 \times 10^6$ ($67.2 \times 10^6$) | 0.0068 | 224.70 | 12 400 (7 700) | 0.815 | 8.44 (27.7) | 10.24 (6.36) |
| Earth | $149.6 \times 10^6$ ($92.96 \times 10^6$) | 0.0167 | 365.26 | 12 742[2] (7 918)[2] | 1.000 | 9.821[3] (32.22)[3] | 11.18 (6.95) |
| Mars | $227.9 \times 10^6$ ($141.6 \times 10^6$) | 0.093 | 686.98 | 6 788 (4 218) | 0.107 | 3.73 (12.3) | 5.03 (3.13) |
| Jupiter[4] | $778 \times 10^6$ ($483 \times 10^6$) | 0.0489 | 4333 | 139 822 (86 884) | 317.8 | 24.79 (81.3) | 59.5 (36.8) |

[1]Mean distance to Earth (center-to-center)
[2]Diameter of sphere of equal volume, based on a spheroidal Earth with a polar diameter of 12 714 km (7900 mi) and an equatorial diameter of 12 756 km (7926 mi)
[3]For nonrotating spherical Earth, equivalent to absolute value at sea level and latitude 37.5°
[4]Note that Jupiter is not a solid body.