9.1 ♣ Sort from smallest mass unit to largest mass unit. (see Section 11.1)

1 oz_m	1 g	1 metric ton	1 kg	1 mg	1 U.S. ton	1 slug	1 lb_m

9.2 ♣ Concepts: What objects have kinetic energy or linear momentum?

${}^{N}K^{S}$, the ***kinetic energy*** of an object S in a reference frame N is to be determined.
Objects S that can have a non-zero kinetic energy are (circle ***all*** appropriate objects):

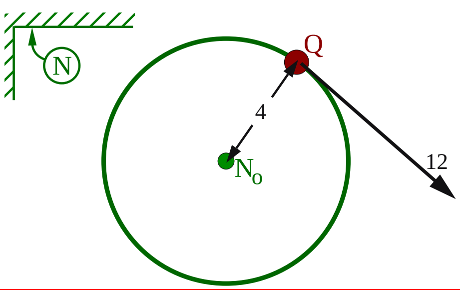
Real number	Matrix	Set of points	Mass center of a rigid body
Vector	Point	Reference frame	Flexible body
3D orthogonal unit basis	Particle	Rigid body	System of particles and bodies

Repeat for ${}^{N}\vec{\mathrm{L}}^{S}$, the ***linear momentum*** of object S in reference frame N [box appropriate objects].

9.3 ♣ Particle angular momentum concepts.

The following figures show a particle Q of mass 1 kg moving in a **plane** N. Point N_o is fixed in N. The figure on the left shows Q moving clockwise with speed 12 on a circle of radius 4 that is centered at N_o. The figure on the right shows Q moving with a speed of 12 on a horizontal line that is 4 from N_o. **Box** the following true statements about Q's ***angular momentum*** in N.

Q's angular momentum about N_o is $\vec{\mathbf{0}}$.
Q's angular momentum about N_o is not $\vec{\mathbf{0}}$.
Q's angular momentum about N_o is $\vec{\infty}$.
Q's angular momentum about N_o does not exist.



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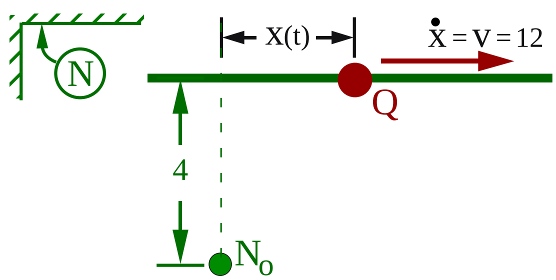


9.4 ♣ Optional: Just for fun. Culture, religion, science and "mass". (Sections , 11.7, 11.6)

Etymology of "mass"	Fill-in the blank
The "m" in $\vec{\mathbf{F}} = m\,\vec{\mathbf{a}}$.	
Jewish Passover flat bread/cracker.	
Greek for flat bread.	
Latin for lump of dough.	
Spanish for lump of dough.	
Catholics eat bread at this Sunday event.	
Approximate number of atoms in 12 grams of carbon-12.	6 x 10
Estimated number of atoms in the visible universe.	1 x 10
Sub-atomic particle responsible for mass in animals, vegetables, and minerals.	
Most expensive science project in history to find sub-atomic particle with mass.	
Possible Earth-fatal object created by aforementioned science project.	

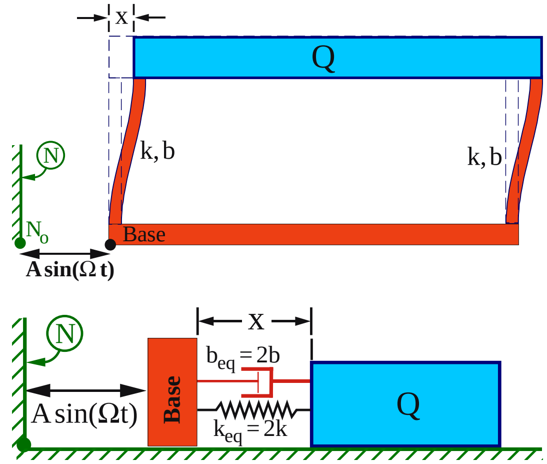
9.5 FE/EIT Review – Motion of a building in an earthquake.

$\vec{\mathbf{F}} \;\Rightarrow\; \vec{\mathbf{F}} = m\,\vec{\mathbf{a}} \;\Rightarrow\; \ddot{x}$

A building moves due to an earthquake. The horizontally-right displacement of the building's base B is **modeled** as $A\sin(\Omega\,t)$ where the constant A is the magnitude of the ground's horizontal displacement and the constant Ω is the earthquake's frequency.

The base motion causes the building's roof Q of mass m to displace horizontally by $x(t)$ from its base. The stiffness and material damping in each of the two columns that support the roof is modeled as a linear horizontal spring (k) and linear horizontal damper (b).

For this dynamic analysis, the system is modeled as shown right (with a spring of 0 natural length). It is helpful to introduce a horizontally-right unit vector $\widehat{\mathbf{n}}_x$.



x is the $\widehat{\mathbf{n}}_x$ measure of Q's position from its base B

(a) Draw Q's ***free-body diagram*** and determine the spring/damper force on Q.
Result: $\quad \vec{\mathbf{F}}_{\text{Spring/Damper}} \underset{\text{FBD}}{=} (-b_{eq}\,\dot{x} \;+\; -k_{eq}\,x)\,\widehat{\mathbf{n}}_x$

FBD of Q

(b) Form the relevant acceleration for $\vec{\mathbf{F}} = m\,\vec{\mathbf{a}}$ (e.g., differentiate the relevant position vector/velocity). Next, dot-product $\vec{\mathbf{F}} = m\,\vec{\mathbf{a}}$ with $\widehat{\mathbf{n}}_x$ to write a differential equation governing $x(t)$.
Result: $\vec{\mathbf{a}} = [\;\_\_\_\; - \;\_\_\_\_\_\_\;]\,\widehat{\mathbf{n}}_x \quad\Rightarrow\quad m\,\ddot{x} \;+\; b_{eq}\,\dot{x} \;+\; k_{eq}\,x \;=\; m\,A\,\Omega^2\,\sin(\Omega\,t)$

(c) Graphed right is $x(t)$ when:

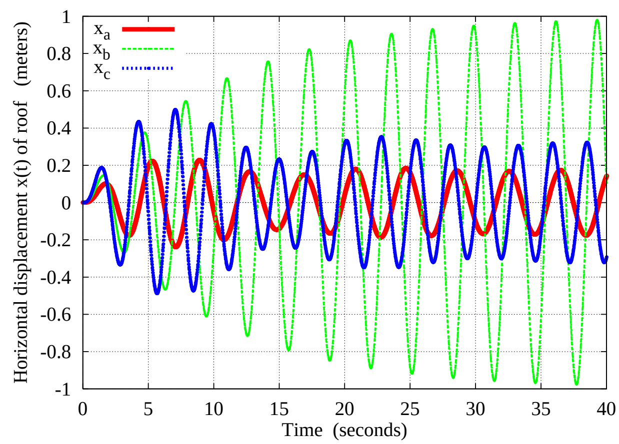
(a) $\Omega \;=\; 0.8\sqrt{\frac{k_{eq}}{m}} \;=\; 0.8\,\omega_n \qquad x_a(t)$

(b) $\Omega \;=\; 1.0\sqrt{\frac{k_{eq}}{m}} \;=\; 1.0\,\omega_n \qquad x_b(t)$

(c) $\Omega \;=\; 1.2\sqrt{\frac{k_{eq}}{m}} \;=\; 1.2\,\omega_n \qquad x_c(t)$

Circle the Ω that corresponds to the largest ***steady-state*** amplitude for $x(t)$.

Note: These graphs use $m \;=\; 5000$ kg, $b_{eq} \;=\; 1000\,\frac{\text{N*sec}}{\text{m}}$, $k_{eq} \;=\; 20000\,\frac{\text{N}}{\text{m}}$, $A \;=\; 0.1$ m.



(d) **Physics** ($\vec{\mathbf{F}} = m\,\vec{\mathbf{a}}$) gives the previous (boxed) equation in terms of positive constants m, b_{eq}, k_{eq}. However, its **mathematics** is easier if that equation is rewritten (rearrange by dividing by m) in terms of the positive constants ζ and ω_n as shown in the boxed-equation below. Determine the building's ***natural frequency*** ω_n and ***damping ratio*** ζ in terms of m, b_{eq}, k_{eq}.
Result:

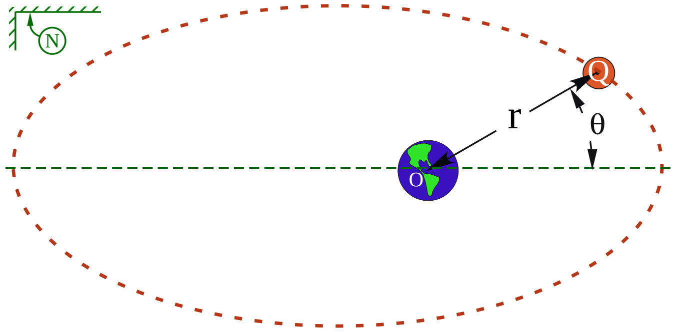
$$\ddot{x} \;+\; 2\,\zeta\,\omega_n\,\dot{x} \;+\; \omega_n^2\,x \;=\; A\,\Omega^2\,\sin(\Omega\,t) \quad\Rightarrow\quad \omega_n = \sqrt{\frac{\_\_\_}{\_\_\_}} \qquad \zeta = \frac{\_\_\_}{2\sqrt{\_\_\_\;\_\_\_}}$$

(e) When $\zeta \;=\; 0$, the building vibrates at ω_n. When $0 \le \zeta \le 1$ (common for many structures), the building vibrates at a ***damped natural frequency*** $\omega_d \triangleq \omega_n\,\sqrt{1-\zeta^2}$.
In general, damping slows things down and makes $\omega_d \;<\; \omega_n$. **True/False**.

9.6 FE/EIT Review – Momentum, energy, and orbital mechanics.

$\vec{\mathbf{F}} \;\Rightarrow\; \vec{\mathbf{F}} = m\,\vec{\mathbf{a}} \;\Rightarrow\; \ddot{r},\ \ddot{\theta}$

The following figure shows a satellite Q (modeled as a particle of mass m) in an elliptical orbit around Earth. Earth is modeled as a particle O fixed in a Newtonian reference frame N.



Draw right-handed orthogonal unit vectors $\widehat{\mathbf{n}}_x$, $\widehat{\mathbf{n}}_y$, $\widehat{\mathbf{n}}_z$ fixed in N with $\widehat{\mathbf{n}}_x$ horizontally-right and parallel to the ellipse's major diameter, $\widehat{\mathbf{n}}_y$ vertically-upward and parallel to the ellipse's minor diameter, and $\widehat{\mathbf{n}}_z$ perpendicular to the ellipse's plane.

Draw right-handed orthogonal unit vectors $\widehat{\mathbf{e}}_r$, $\widehat{\mathbf{e}}_\theta$, $\widehat{\mathbf{e}}_z$, with $\widehat{\mathbf{e}}_r$ from O to Q and $\widehat{\mathbf{e}}_z = \widehat{\mathbf{n}}_z$.

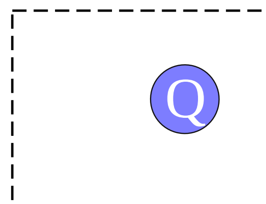
Quantity	Symbol	Type	Value
Universal gravitational constant	G	Constant	6.67×10^{-11} N∗m²/kg²
Mass of Earth O	m^E	Constant	5.97×10^{24} kg
Mass of Q	m	Constant	200 kg
Angle between line OQ and long axis of the ellipse	θ	Variable	Initial value
Distance between O and Q	r	Variable	Initial value

(a) Form Q's ***linear momentum***, ***angular momentum*** about O, and ***kinetic energy*** in N.
Result: (in terms of symbols in the previous table, their time-derivatives, and $\widehat{\mathbf{e}}_r$, $\widehat{\mathbf{e}}_\theta$, $\widehat{\mathbf{e}}_z$).

$${}^N\vec{\mathrm{L}}^Q \underset{(10.1)}{=} m(\;\_\_\_\; + \;\_\_\_\;) \qquad {}^N\vec{\mathrm{H}}^{Q/O} \underset{(10.3)}{=} \;\_\_\_\; \qquad {}^N K^Q \underset{(10.6)}{=} \frac{1}{2} m[\;\_\_\;^2 + (\;\_\_\;)^2]$$

(b) **Draw** Q's free-body diagram and determine the resultant force on Q.
Dot $\vec{\mathbf{F}}^Q = m\,{}^N\vec{\mathbf{a}}^Q$ with "clever" unit vectors and solve for $\ddot{r}$ and $\ddot{\theta}$.
Result:

$$\vec{\mathbf{F}}^Q = \frac{-G\,m^E\,m}{r^2}\,\widehat{\mathbf{e}}_r \qquad \ddot{r} = \;\_\_\_\; - \frac{\_\_\_}{r^2} \qquad \ddot{\theta} = \frac{\_\_\_}{r}$$



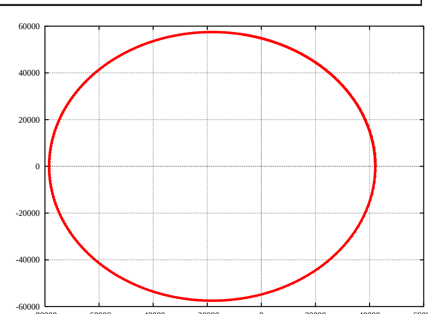
(c) Form an expression for Q's mechanical energy in N (sum of kinetic energy and potential energy U).
Result: ***Conservation of mechanical energy*** $\quad \text{KePe} = \frac{1}{2}\,m\left[\dot{r}^2 + (\dot{\theta}\,r)^2\right] - \frac{G\,m\,m^E}{r}$

(d) **Optional:** Starting with the ***angular momentum principle*** in equation (20.4), form an expression that stays constant during Q's motion in N ***(conservation of angular momentum)***.
Result: $\quad H_{\text{Constant}} \underset{(20.10)}{=} \;\_\_\_\;$ (Section 20.8)

(e) **Draw** a line L tangent to the ellipse at Q and perpendicular to $\widehat{\mathbf{n}}_z$.

In general,	${}^N\vec{\mathbf{v}}^Q$ (Q's velocity in N) is parallel to $\widehat{\mathbf{e}}_\theta$.	**True/False**
In general,	$\widehat{\mathbf{e}}_\theta$ is parallel to L.	**True/False**
In general,	${}^N\vec{\mathbf{v}}^Q$ is parallel to L.	**True/False**

(f) Shown right is a plot of Q's orbital trajectory when the differential equations from part (6b) are solved. Query the Internet (or a textbook, instructor, colleague, etc.) for the next answers.



- Clearly mark Earth's location on the plot.
- The Earth is located at (circle one):
  the center of the ellipse/a focus of the ellipse.