FOURTH MIDTERM - REVIEW PROBLEMS

A solution set for these review problems is available on the course web site. A data sheet and an integral table are provided.

1. [No solution available.] A traveling wave is described by the function

\[ y = (1.73 \text{ mm}) \sin \left( 27.0x + 5720t + \frac{\pi}{6} \right) \]

Except where shown, all distances are in meters. Other quantities are in the usual and appropriate units.

(a) Calculate the magnitude of the velocity of the wave. 
(b) Specify in words, the direction of the wave. 
(c) Calculate the wavelength. 
(d) Calculate the frequency in Hertz. 
(e) At \( t = 0 \), calculate the first positive value of \( x \) for which \( y = 0 \).

2. Assume that on the moon the intensity of sunlight is 1300 W/m\(^2\).

(a) Calculate the maximum instantaneous value of the electric field in the sunlight.
(b) Calculate the maximum instantaneous value of the magnetic field in the sunlight.
(c) If the 30.0% of the sunlight is reflected, calculate the radiation force on an area of 175 m\(^2\) that is perpendicular to the sunlight.
(d) If Jupiter is exactly 5.00 times as far from the sun as the moon is, calculate the value of the Poynting vector at Jupiter.

3. (a) Sunlight strikes the physics parking lot at an angle of 27° from the vertical, as shown. If the intensity arriving at the parking lot surface is 525 W/m\(^2\), calculate the effective \( E_{\text{max}} \) for the light.

4. [No solution available.] The electric field in a light wave is described by (where \( x \) is in meters and \( t \) is in seconds)

\[ E = (0.075 \text{ V/m}) \cos \left( [1.57 \times 10^{-9}]x - [4.71 \times 10^{15}]t \right) \]

(b) Calculate the maximum value of the magnetic field in this light wave. 
(c) Calculate the wavelength of the light. 
(d) Calculate the frequency of this light in Hz. 
(e) Calculate the magnitude of the average value of the Poynting vector for this light.

5. A traveling wave is described by the function

\[ y = (2.45 \text{ mm}) \cos \left( 62.5x + 7520t - \frac{\pi}{9} \right) \]

Except where shown, lengths are in meters. Other quantities are in the usual appropriate units.

(a) Calculate the magnitude of the velocity of the wave. 
(b) Calculate the transverse velocity at \( t = 10.0 \text{ s} \) and \( x = 0 \). 
(c) Calculate the wavelength. 
(d) Calculate the frequency in Hertz. 
(e) Calculate the first value of the time, \( t \), for \( t > 0 \) such that a positive peak of the wave is at \( x = 0 \).
6. The electric field in a laser beam is described by the following function:

\[ E = (2.15 \times 10^{-3} \text{ V/m}) \sin([1.25 \times 10^{7}]x - [3.65 \times 10^{15}]t) \]

where \( x \) is in meters and \( t \), in seconds.

(a) Calculate the wavelength of the light in nm. 
(b) Find the frequency, \( f \), for this light in Hz. 
(c) What is the average value of the Poynting vector for this light? Use the true value of \( c \).
(d) Calculate the velocity of the wave described by this function (not the true value of the velocity of light).
(e) Determine the maximum value of the magnetic field using the true value of the velocity of light. 
(f) A wire carries a current in the direction shown. If the magnitude of the current is decreasing, what is the direction, clockwise or counter clockwise, of the current in the loop. Both the wire and loop are in the plane of the paper.

7. The following describes the \( E \) field of an electromagnetic wave:

\[ E = (4.20 \times 10^{-4} \text{ N/C}) \cos(6.12 \times 10^{7} x + 1.50 \times 10^{9} t - \pi/3) \]

(a) Calculate the maximum value for the magnetic field for this wave.
(b) Calculate the wavelength.
(c) Calculate the frequency.
(d) Calculate the average value of the Poynting vector for the wave.
(e) Is the wave moving in the positive or negative x-direction? Explain.

8. (a) Calculate the critical angle for total internal reflection of diamond (\( n = 2.42 \)).
(b) Light approaches an air-water surface from below at an angle of 27.2° from the normal. Water has \( n = 1.33 \). Calculate the angle \( \phi \) from the emerging beam.
(c) A red laser has a wavelength of 654 nm. Calculate the wavelength in glass of \( n = 1.65 \).
(d) Sunlight is incident on the Physics parking lot with \( S_v = 727 \text{ W/m}^2 \). Calculate the maximum value of the electric field in this light beam.

9. A glass bar has a rectangular cross section as shown. Its index of refraction is 1.62. Light is incident from the left as shown, at an angle \( \phi \) with respect to the normal. The bar is wide enough (left to right in the drawing) that the refracted beam does strike the top surface. Take \( \phi = 27.0^\circ \).

(a) Calculate which face (top, right-hand end, or bottom) the beam emerges from.
(b) Calculate the direction of the beam with respect to the normal to that surface.
(c) Show on a clear drawing the emergent beam and the angle you have calculated.

10. (a) What is the critical angle for total internal reflection of a diamond immersed in water (use light of \( \lambda = 589 \text{ nm} \)).
(b) If the microwaves in your oven have a frequency of 800 MHz, calculate their wavelength.
(d) Sunlight is incident on a solar reflector with an intensity of 655 W/m². Calculate the peak value of the electric field in this light beam.
(e) Calculate the force on 1.00 m² of the solar collector in (d) if 20% of the light is reflected and 80% absorbed. (Intensity is the same as in (d).)
11. Calculate the maximum angle of incidence, $\theta$, for which no light emerges from the right-hand face of prism. The prism is made of glass of $n = 1.55$.

12. Given a glass prism ($n = 1.55$) with vertex angle $30^\circ$, as shown in cross section. Light is incident normally on the base to the left of the center line. Calculate the direction the light beam leaves the prism. State clearly which face it leaves, and the angle with respect to the normal of that face. Show on a drawing your definition of that angle.

13. A glass prism with an apex of $60^\circ$ has $n = 1.60$.
   (a) What is the smallest angle of incidence for which a ray can enter one face of the prism and emerge from the other?
   (b) What angle of incidence would be required for the ray to pass through the prism symmetrically, as shown in the figure.

14. (a) Calculate the critical angle for total internal reflection for a diamond ($n = 2.42$) in water ($n = 1.33$).
   (b) Green light in air has a wavelength of 500 nm. Calculate its wavelength in diamond.
   (d) Light is incident on the prism shown at the angle of minimum deviation. Take the index of the prism as $n = 1.65$, and calculate $\phi$, the angle of deviation.
   (e) Sunlight is incident at angle of $30^\circ$ from the vertical on the physics parking lot. If $S_{\lambda \nu} = 750$ W/m$^2$, and the parking lot has an area of 100 m$^2$, calculate the radiation force on the lot assuming complete absorption.

15. Given a $30^\circ$-$60^\circ$-$90^\circ$ prism as shown with an index of 1.55. Light is incident from air perpendicular to the base. Calculate from which face, A or B, the light leaves the prism, and shown on a clear drawing its direction, with a numerical value for the angle.
16. A 45°-45°-90° prism of glass with refractive index 1.55 is immersed in water (refractive index 1.33).

(a) Light is incident perpendicular to the base as shown. Calculate the direction of refracted ray (measured from the normal) emerging from the prism at surface (A).

(b) Find the minimum angle of incidence to the base where the beam is totally internally reflected at surface (A).

(c) Find the face, (A), (B) or (C), and angle that the beam in (b) emerges from the prism.

17. The charge on a capacitor in the simple RLC circuit shown is given by

\[ Q = (1.25 \text{ mC}) \left[ \cos \omega t \right] e^{-\frac{R}{2L}t} \]

Assume \(2L/R >> T\), where \(T\) is the period of the oscillations.

(a) Find the current in the inductor as a function of time. The arrow indicates the direction of positive current, and the signs on the capacitor, its polarity when positively charged.

(b) Calculate the total energy in the electrical oscillation at \(t = 2L/R\).

\[ R = 150 \, \Omega; \quad L = 225 \, \text{mH}; \quad C = 14.0 \, \text{pF} \]

18. (a) Given a rectangular toroid with the cross section shown and \(N\) turns of wire, calculate its inductance.

(b) If \(N = 450\), \(a = 2.45\) cm, \(b = 8.75\) cm and \(c = 1.25\) cm, calculate the numerical value for the inductance.

(c) When the current is 1.65 A, calculate the magnetic energy stored in the toroid between \(R = 1.25\) cm and \(R = 7.00\) cm. [Answer to (a) not needed.]

19. (a) Calculate the critical angle for total internal reflection for diamond (\(n = 2.40\)) in water (\(n = 1.33\)).

(b) Find the polarizing angle for light incident on a diamond (\(n = 2.40\)) surface from air.

(c) If microwaves have a wavelength of 1.30 cm, calculate their frequency.

(d) Unpolarized light is incident on three polarizing sheets, such as shown in class. The axis of B is at 30° with respect to A. The axis of C is at 30° with respect to B. If \(I_i\) is the incident intensity, what is the intensity after passing C?

(e) Sunlight is incident on a solar collector with an intensity of 455 W/m². What is the peak value of the magnetic field in the light waves?

20. Light enters the prism shown parallel to the base. The index of refraction of the prism is 1.55.

(a) Calculate the angle in air, measured with respect to the normal, of the light path when it leaves the prism.

(b) At what minimum angle, with respect to the normal of side A, should the light enter the prism such that there is total internal reflection at side B?
21. The magnetic field of light being emitted from a laser is described by

\[ B = 3.50 \times 10^{-9} \, \text{T} \cos (1.32 \times 10^{7} x - 3.22 \times 10^{15} t) \]

(a) Calculate the wavelength, in nm, of this light.
(b) Find the frequency, \( f \), of this light (in Hz).
(c) What is the average value of the Poynting vector (use the true value of \( c \)).
(d) Find the velocity of this wave calculated from the function above.
(e) What is the peak value of the electric field in this wave? (Use the true value of \( c \)).

22. A coaxial cable consists of an inner conductor of outer radius \( a \), and a thin outer conductor of inner radius \( b \). A current \( I_0 \) (\( I_0 = 3.22 \, \text{A} \)) flows on the inner conductor and back on the outer conductor.

(a) Calculate the energy stored in the magnetic field between the conductors for a length \( \ell = 2.25 \, \text{m} \) of this cable.
(b) Using the result above, calculate the inductance of \( 3.75 \, \text{m} \) of this cable.

23. A beam of laser light has an electric field described by:

\[ E = (4.00 \times 10^{7} \, \text{V/m}) \cos [(1.25 \times 10^{14})x + (4.75 \times 10^{14})t] \]

where \( x \) is in meters and \( t \) in seconds.

(a) Calculate the wavelength of the light in nm.
(b) Calculate the frequency, \( f \), for this light.
(c) Calculate the velocity for this light wave (not the true value of \( c \), but close).
(d) Calculate the energy density at the maximum value of the electric field.
(e) Calculate the instantaneous value of the Poynting vector at the maximum of the electric field. Use the true value of \( c \), if needed.

24. In the drawing shown, the switch \( S_1 \) is closed for a long time with \( S_2 \) open. At \( t = 0 \) \( S_1 \) is opened and then \( S_2 \) is closed.

(a) Write an expression with numerical values for the charge on the capacitor as a function of time.
(b) Calculate the maximum energy stored in the inductor.
(c) Calculate the maximum value of the current in the inductor.

\[ \varepsilon = 250 \, \text{V}; \, R = 175 \, \Omega; \, L = 87.0 \, \text{mH}; \, C = 140 \, \text{pF} \]

25. (a) A diffraction grating has 5000 lines/cm. Laser light of 650 nm (red) is sent through this grating at normal incidence. What is the angle of the second order spot that comes out?
(b) In a two-slit interference experiment the fifth, tenth, and fifteenth order spots are missing. If the slit separation is 0.275 mm, what is the slit width?
(c) Calculate the critical angle for total internal reflection for a diamond (\( n = 2.40 \)) immersed in water (\( n = 1.33 \)).
(d) Calculate the polarizing angle for diamond (\( n = 2.40 \)) immersed in water (\( n = 1.33 \)), where the light is incident from the water.
(e) The intensity of sunlight is observed to be 980 W/m² in a plane perpendicular to the light beam. Calculate the peak value of the magnetic field in this light.
(f) Laser light of wavelength 550 nm is incident on a single slit. On a screen 4.50 m away the two minima on either side of the center are 2.00 cm apart. Calculate the width of the slit.
26. An LC circuit includes a 30.0 μF capacitor and has a period of 2.50 ms. The peak value of the current is 13.0 mA.
   
   (a) Calculate the inductance in the circuit.
   (b) Calculate the peak value of the charge on the capacitor.

27. After being open for a long time, the switch in this circuit is closed for 0.500 s; it is then opened at \( t = 0 \). If you cannot get the time constant in (a), use a symbol \( \tau \) for the time constant in (a) and (b).

   (a) Calculate the current in the inductor at \( t = 0 \).
   (b) Calculate the current in the inductor at \( t = 0.100 \) s. Do not use a symbol for this second time constant.

   \[ R_1 = 100 \, \Omega; \, R_2 = 200 \, \Omega; \, L = 15.0 \, H; \, \varepsilon = 175 \, V \]

28. (a) Calculate the critical angle for total internal reflection for a diamond (\( n = 2.42 \)) immersed in water (\( n = 1.33 \)).

   (b) Calculate the polarizing angle for light incident from air onto water (\( n = 1.33 \)).

   (c) Unpolarized light is incident on three polarizing sheets, such as shown in class. The axis of \( B \) is at 20° with respect to the axis of \( A \). The axis of \( C \) is at 40° with respect to the axis of \( B \). If \( I_0 \) is the incident intensity, what is the intensity after passing \( C \)?

   (d) Sunlight is incident on a solar sail with an intensity of 600 W/m². If you assume perpendicular incidence and complete reflection, what is the pressure on the sail (in N/m²)?

   (e) If \( C_1 = 6.00 \, \mu F, \, C_2 = 9.00 \, \mu F \) and the inductor is 1.25 mH, calculate the oscillation frequency of the system shown.

29. The electric field in an electromagnetic wave in a vacuum can be described by the following:

   \[ E = (0.0027 \, V/\text{m}) \sin \left(3.25 \times 10^7 x + 9.74 \times 10^{15} t\right) \]

   (a) Calculate the wavelength of this light.
   (b) Calculate the frequency (in Hz) of this light.
   (c) Calculate the average value for the Poynting vector for this light.
   (d) Calculate the maximum value of the magnetic field in this light beam.
   (e) Giving a clear reason, state whether the beam is moving in the positive or negative x-direction.

30. The prism shown has the angles given. It is made of glass with index of refraction of 1.50. Light enters the prism perpendicular to the base, as shown.

   (a) Show clearly (making your reasoning clear) which face the beam of light emerges from, A or B.
   (b) Calculate the direction of the emerging beam with respect to the normal of the face it emerges from.
31. (a) Calculate the critical angle for total internal reflection for a high-index glass with index of refraction 
\( n = 1.75 \).

(b) A green laser has a wavelength of 500 nm in air. Calculate the wavelength of this light in a diamond 
\( n = 2.42 \).

(c) Light approaches the surface of a diamond from inside the diamond at an angle of incidence of 18.0°. At 
what angle does it leave the diamond in air \( n = 2.42 \)?

(d) A diffraction grating has 6000 lines/cm. Green laser light \( \lambda = 500 \text{ nm} \) is sent through this grating at 
normal incidence. At what angle does the third order bright spot come out?

(e) Calculate the polarizing angle at the glass-water interface for glass \( n = 1.55 \) immersed 
in water \( n = 1.33 \).

32. A beam of laser light has an electric field described by:

\[ E = 2.75 \times 10^{-2} \text{ V/m} \cos \left[ (2.75 \times 10^{14}) t - (8.65 \times 10^{14}) t \right] \]

where \( x \) is in meters and \( t \) in seconds.

(a) Calculate the wavelength of the light wave.

(b) Find the frequency, \( f \), for this light wave.

(c) Determine the velocity of this light wave (not \( c \), but close).

(d) What is the energy density at the maximum value of the electric field?

(e) Using the true velocity of light (c), calculate the maximum value of the magnetic field.

33. A 60°-60°-60° prism is made of diamond \( n = 2.42 \). Light is incident parallel to the 
base as shown.

(a) Calculate the direction inside the prism, measured as an angle (specify 
clockwise or counterclockwise) from the incident beam, that the light travels 
after entering the prism.

(b) Determine from which face A, B or C, the light emerges from the prism.

(c) Calculate the direction, with respect to the normal of that face (A, B or C), for 
the emergent beam.

34. Given the lens set-up shown, you supply the sign of the focal length 
from the drawing.

(a) Calculate the position of the final image measured from lens 
B. (+ to the right; - to the left.)

(b) Calculate the magnification of the system.

(c) Is the final image real or virtual? State your reasoning.

(d) Is the final image erect or inverted? State your reasoning.

35. (a) Calculate the critical angle for total internal reflection for a diamond \( n = 2.40 \) immersed in water 
\( n = 1.33 \).

(b) Light is incident from water \( n = 1.33 \) on glass \( n = 1.55 \) at an angle of 33.0°. What is the angle of 
refraction in the glass?

(c) A Young’s two-slit interference experiment is performed with monochromatic light. The separation 
between the slits is 0.750 mm, and the interference pattern on a screen 4.25 m away shows the first side 
maximum 3.25 mm from the center of the pattern. What is the wavelength of the incident light?

(d) A soap film \( n = 1.33 \) is viewed in reflection at perpendicular incidence. Bright reflection is observed 
with a wavelength of \( \lambda = 650 \text{ nm} \). What is the minimum thickness of the soap film from this information?

(e) A concave spherical mirror has a radius of curvature of 1.30 m. Calculate the position of the image of an 
object 1.55 m away from the mirror. Distances are measured along the optic axis.
36. Given the lens system shown with a real object 135 cm to the left of lens 1. You supply the signs for the focal lengths.

(a) Calculate the position, right or left of lens 1, and the distance for the image just of lens 1.
(b) Is the image in (a) real or virtual?
(c) Calculate the position, measured from lens 2, distance and right or left, of the final image in this system.
(d) Is the final image erect or inverted, with respect to the original object? Justify your answer.

37. Light is incident perpendicular to the base of a glass prism of index angle 22.0°. The index of the prism is n = 1.55.

(a) Calculate which face 1, 2 or 3, the light emerges from. Show your work.
(b) Calculate the angle, with respect to the normal of the face, of the emergent beam, outside of the prism.

38. A film of oil (n = 1.24) on glass (n = 1.55) is observed in perpendicular reflection.

(a) A minimum in reflection is observed for both \( \lambda = 660 \text{ nm} \) and \( \lambda = 540 \text{ nm} \). What is the minimum thickness of the oil film from this data?
(b) The film thickness is increased slowly until a minimum is again found for both of the above wavelengths in reflection. What is the new thickness? [Hint: \( m_1 \) and \( m_2 \) are integers and between 10 and 20.]

39. (a) Calculate the critical angle for total internal reflection for a high index glass with n = 1.72.
(b) Yellow light has a wavelength of 590 nm in air. Calculate its wavelength in diamond (n = 2.42).
(c) In a two slit interference experiment, light of \( \lambda = 650 \text{ nm} \) is perpendicularly incident on two slits that have a separation of 0.175 mm. Calculate the displacement from the center of the pattern on a screen 4.50 m away to the next bright spot.
(d) Light approaches the surface of a diamond (n = 2.42) from inside at an angle of incidence of 16.0°. What is the angle in air for the emergent beam?
(e) White light is incident on a soap film whose thickness is 0.0132 mm. Calculate the wavelength separation for two bright colors in reflection near \( \lambda = 500 \text{ nm} \). The soap film has index n = 1.33.

40. The magnetic field in a laser beam of light can be described by the function

\[ B = (3.02 \times 10^{-10} \text{T}) \cos \left[ \left( 1.14 \times 10^7 \text{ m}^{-1} \right)x + \left( 3.75 \times 10^{15} \text{ s}^{-1} \right)t \right] \]

(a) Calculate the wavelength of the light in nanometers.
(b) Calculate the frequency, f, of the light in Hertz.
(c) Calculate the magnitude of the velocity as described by this function (not the true value of c).
(d) Using the true value of c, calculate the maximum value of the electric field in the light beam
(e) Is the direction of the wave in the positive or negative x-direction? Explain.

41. Given a 40°-50°-90° prism as shown with an index of refraction of n = 1.65. Light is incident from air perpendicular to the base. Calculate from which face, A or B, the light leaves the prism, and show on a clear drawing its direction, with a numerical value for the angle.
42. Given the lens system shown with a real object 145 cm to the left of lens 1. You supply the signs for the focal lengths. 

(a) Calculate the position, right or left of lens 1, and the distance for the image just of lens 1. 
(b) Is the image in (a) real or virtual? 
(c) Calculate the position, measured from lens 2, distance and right or left, of the final image in this system. 
(d) Is the final image erect or inverted, with respect to the original object? Justify your answer.

43. Given the description below for the electric field in a light beam (x is in meters, t in seconds),

\[ E = (0.325 \, \text{V/m}) \sin \left( (5.23 \times 10^{-6})x + (1.20 \times 10^{14})t \right) \]

(a) Calculate the magnitude of the speed of this wave. 
(b) Clearly state the direction of the wave. 
(c) Calculate the maximum value of the B field (use the true velocity of the light in this calculation). 
(d) Find the wavelength (in meters) of the wave. 
(e) Calculate the frequency of the wave (in Hz).

44. Given the lens system shown.

(a) Calculate the position, measured with respect to the original object as \( x = 0 \), of the final image. 
(b) Find the magnification, including sign, of the final image. 
(c) Is the final image real or virtual? For full credit, give an explanation.

45. In a 2-slit experiment, the slits are narrow and a distance apart of 0.175 mm. Yellow light (\( \lambda = 594.0 \, \text{nm} \)) is incident from the left, perpendicular to the slits and screen.

(a) If \( y = 0 \) is exactly opposite to the slits, calculate the position of the third dark band from the center. 
(b) If light that is a mixture of \( \lambda = 600 \, \text{nm} \) and \( \lambda = 650 \, \text{nm} \) is incident on the slits, determine the position closest to \( y = 0 \) where their maxima overlap exactly.

46. A prism, made of diamond (n = 2.40), is immersed in water (n = 1.33). Light is incident perpendicular to the base as shown.

(a) How many total internal reflections occur before some of the beam leaves the prism? 
(b) Which face, A or B does it leave? 
(c) Calculate the angle, with respect to the normal to that face, of the emergent beam.

47. (a) Calculate the critical angle for total internal reflection for glass (n = 1.55) immersed in water (n = 1.33). 
(b) A concave spherical mirror has a radius of curvature of 1.20 m. Calculate the position of the image of an object 1.45 m away from the mirror. 
(c) A soap film (n = 1.33) is observed to show a reflection maximum in perpendicular incidence at a green wavelength of 525 nm. What is the minimum thickness of the soap film you can deduced from this data? 
(d) Sunlight is incident on the physics parking lot with an intensity of 750 W/m². Calculate the maximum value of the magnetic field in this light beam. 
(e) A green laser has a wavelength of 525 nm. Calculate its wavelength in diamond (n = 2.40).
48. For the lens system shown, there is a real object 250 cm to the left of lens 1. You supply the sign for the focal lengths of the lenses.

(a) Calculate the position, measured from the center of lens 2, of the final image (+ right, - left).
(b) Is the image erect or inverted?
(c) Is the image real or virtual?
(d) Calculate the magnification of the system.

49. A prism (shown in the drawing) is created of diamond (n = 2.40). Light is incident perpendicular to the bottom of the prism.

(a) How many total internal reflections occur before the beam exits the prism?
(b) Which face, A or B, does it exit?
(c) What is the angle of the emergent beam in air with respect to the normal of that face?

50. Light of 2 colors, $\lambda = 500$ nm and $\lambda = 600$ nm, is perpendicularly incident on a 2-slit system. The slit separation is 0.250 mm. The distance to the observing screen is 5.25 m.

(a) Calculate the separation, in cm, between the $m = 0$ and $m = 1$ bright fringes on the screen for the $\lambda = 500$ nm light.
(b) Calculate the first two angles where the maximum of the two colors exactly overlap.
**Data:** Use these constants (where it states, for example, 1 ft, the 1 is exact for significant figure purposes).

1 ft = 12 in (exact)  
1 m = 3.28 ft (exact)  
1 mile = 5280 ft (exact)  
1 hour = 3600 sec = 60 min (exact)  
1 day = 24 hr (exact)  
g\(_{\text{earth}}\) = 9.80 m/s\(^2\) = 32.2 ft/s\(^2\)  
g\(_{\text{moon}}\) = 1.67 m/s\(^2\) = 5.48 ft/s\(^2\)  
1 year = 365.25 days  
1 kg = 0.0685 slug  
1 N = 0.225 pound  
1 horsepower = 550 ft·pounds/s (exact)  

\(M_\text{earth} = 5.98 \times 10^{24}\) kg  
\(R_\text{earth} = 6.38 \times 10^3\) km  
\(M_\text{sun} = 1.99 \times 10^{30}\) kg  
\(R_\text{sun} = 6.96 \times 10^{8}\) m  
\(M_\text{moon} = 7.35 \times 10^{22}\) kg  
\(R_\text{moon} = 1.74 \times 10^3\) km  
\(G = 6.67 \times 10^{-11}\) N·m²/kg²  
\(k = 8.99 \times 10^9\) N·m²/C²  
\(\epsilon_0 = 8.85 \times 10^{-12}\) F/m  
\(\epsilon_{\text{electron}} = -1.60 \times 10^{-19}\) C  
\(m_{\text{electron}} = 9.11 \times 10^{-31}\) kg  
\(\mu_0 = 4\pi \times 10^{-7}\) T·m/A (exact)  

N(Avogadro's No.) = \(6.02 \times 10^{23}\) atoms/gm·mole  
= \(6.02 \times 10^{26}\) atoms/kg·mole  
1 Tesla = 10,000 gauss (exact)  
\(\rho(\text{H}_2\text{O}) = 1000\) kg/m³  
\(c_{\cos(a \pm b)} = c_{\cos a}\ cos b \pm a\ sin b\)  
\(c_{\sin(a \pm b)} = c_{\sin a}\ cos b \pm \sin b\)  
\(m_{\text{proton}} = 1.67 \times 10^{-27}\) kg  
\(h = 6.64 \times 10^{-34}\) J  
\(\pi = 3.14\)  
\(c = 3.00 \times 10^8\) m/s