Last Name:_______First Name________Network-ID_________
Discussion Section:________Discussion TA Name:______________________________

Instructions—
Turn off your cell phone and put it away.
This is a closed book exam. You have ninety (90) minutes to complete it.

1. Use a #2 pencil; do **not** use a mechanical pencil or a pen. Fill in completely (until there is no white space visible) the circle for each intended input – both on the identification side of your answer sheet and on the side on which you mark your answers. If you decide to change an answer, erase vigorously; the scanner sometimes registers incompletely erased marks as intended answers; this can adversely affect your grade. Light marks or marks extending outside the circle may be read improperly by the scanner.

2. Print your last name in the **YOUR LAST NAME** boxes on your answer sheet and print the first letter of your first name in the **FIRST NAME INI** box. Mark (as described above) the corresponding circle below each of these letters.

3. Print your NetID in the **NETWORK ID** boxes, and then mark the corresponding circle below each of the letters or numerals. Note that there are different circles for the letter "I" and the numeral "1" and for the letter "O" and the numeral "0". **Do not** mark the hyphen circle at the bottom of any of these columns.

4. **You may find the version of this Exam Booklet at the top of page 2**. Mark the version circle in the **TEST FORM** box at the bottom on the front side of your answer sheet.

5. Print your UIN# in the **STUDENT NUMBER** designated spaces and mark the corresponding circles. You need not write in or mark the circles in the SECTION box.

6. On the **SECTION** *line*, print your **DISCUSSION SECTION**. (You need not fill in the COURSE or INSTRUCTOR lines.)

7. Sign **(DO NOT PRINT)** your name on the **STUDENT SIGNATURE** *line*.

Before starting work, check to make sure that your test booklet is complete. You should have 11 ***numbered pages*** *that include two (2) Formula Sheets.*

Academic Integrity — **Giving assistance to or receiving assistance from another student or using unauthorized materials during a University Examination can be grounds for disciplinary action, up to and including dismissal from the University.**

This Exam Booklet is Version A. Mark the **A** circle in the TEST FORM box at the bottom on the front side of your answer sheet.

Exam Grading Policy —
The exam is worth a total of more than 100 points, and will be scaled to 100 points. It is composed of three types of questions:

MC5: *multiple-choice-five-answer questions, each worth 6 points.*
Partial credit will be granted as follows.
(a) If you mark only one answer and it is the correct answer,
you earn **6** points.
(b) If you mark *two* answers, one of which is the correct answer,
you earn **3** points.
(c) If you mark *three* answers, one of which is the correct answer, you earn **2** points.
(d) If you mark no answers, or more than *three*, you earn 0 points.

MC3: *multiple-choice-three-answer questions, each worth 3 points.*
No partial credit.
(a) If you mark only one answer and it is the correct answer,
you earn **3** points.
(b) If you mark a wrong answer or no answers, you earn **0** points.

TF: *true-false questions, each worth 2 points.*
No partial credit.

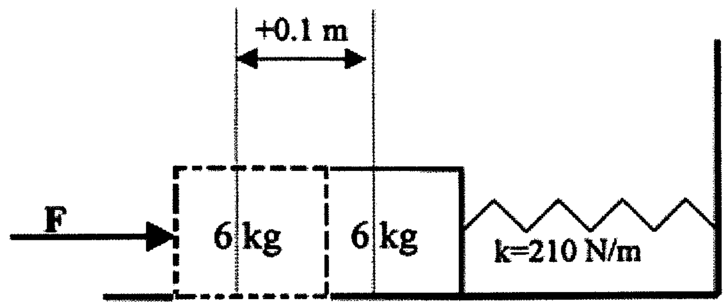
(a) If you mark only one answer and it is the correct answer, you earn **2** points.
(b) If you mark the wrong answer or neither answer, you earn **0** points.

Unless told otherwise, you should assume that the acceleration of gravity near the surface of the earth is 9.8 $\mathrm{m/s^2}$ *downward and ignore any effects due to air resistance.*

The following 3 questions concern the same physical situation:

A block is sitting on a horizontal frictionless surface. It is attached to a massless spring in its equilibrium length. A force F is applied to the block, compressing the spring from its equilibrium length by 0.1 m as shown. The force is then abruptly released allowing the block to oscillate.

Given: The mass of the block is $M = 6.0$ kg. The spring constant $k = 210$ N/m.



1. Determine the magnitude of the force F.

a. 8 N
b. 10 N
c. 17 N
d. 18 N
(e.) 21 N

$F = -kx$
$= -210\ \text{N/m} \times 0.1\ \text{m}$
$= -21\ \text{N}$

2. What is the period of the oscillation?

a. 0.01 s
b. 0.3 s
(c.) 1.1 s
d. 1.4 s
e. 9.3 s

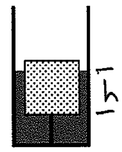
$T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{6\ \text{kg}}{210\ \text{N/m}}} = 1.06\ \text{s}$

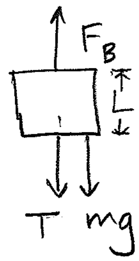
3. If the applied force, F, is doubled to 2F the oscillation period

a. increases.
b. decreases.
(c.) stays the same.

The following 3 questions concern the same physical situation:

A plastic cube, 10 cm (L) on a side, is floating in a bath of heavy oil as shown. The cube is tied to the bottom of the bath with a string so that 8 cm (h) of the cube is below the surface of the heavy oil. The density of the plastic is 0.65 g/cm^3, and the density of the heavy oil is 1.75 g/cm^3.





4. What is the tension in the string?

a. 0.75 N
b. 6.37 N
(c.) 7.35 N
d. 13.72 N
e. 17.15 N

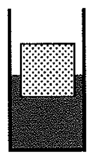
$T + mg = F_B$

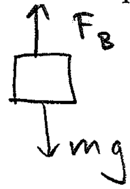
$T = F_B - mg = \rho_{oil}\, g\, h \times L^2 - \rho_{plastic} L^3 g$

$= 1.75\ g/cm^3 \times 9.8\ m/s^2 \times 8\ cm \times (10\ cm)^2 - 0.65\ g/cm^3 \times (10\ cm)^3 \times 9.8\ m/s^2$

$= 7350\ g\,\frac{m}{s^2} = 7.35\ kg\ m/s^2 = 7.35\ N$

5. Now the string is cut as shown. How much of the cube is below the surface of the heavy oil? (Note that the vertical placement of the plastic cube is not drawn to scale.)





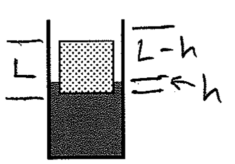
a. 0.65 cm
b. 1.54 cm
c. 2.69 cm
(d.) 3.71 cm
e. 6.50cm

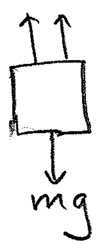
$F_B = mg$

$\rho_{oil}\, g\, h \times L^2 = \rho_{plastic} \times L^3 \times g$

$h = \frac{\rho_{plastic}}{\rho_{oil}} \times L = \frac{0.65}{1.75} \times 10\ cm = 3.71\ cm$

6. Now after the string has ben cut, light oil with a density of 0.50 g/cm^3 is poured in the bath to make an additional layer 10 cm deep. How much of the cube is below the surface of the heavy oil? (Note that the vertical placement of the plastic cube is not drawn to scale.)





(a.) 1.20 cm
b. 2.86 cm
c. 3.71 cm
d. 5.00 cm
e. 7.71 cm

$F_B^{oil} + F_B^{light\ oil} = mg$

$\rho_{oil}\, g\, h \times L^2 + \rho_{light\ oil}\, g\, (L-h) L^2 = \rho_{plastic} \times L^3 \times g$

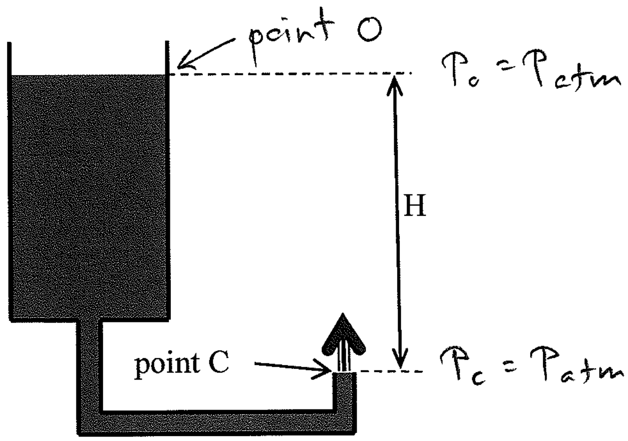
$h(\rho_{oil} - \rho_{light\ oil}) = \rho_{plastic} L - \rho_{light\ oil} L$

$h = L\, \frac{\rho_{plastic} - \rho_{light\ oil}}{\rho_{oil} - \rho_{light\ oil}} = \frac{0.65 - 0.5}{1.75 - 0.5} \times 10\ cm = 1.2\ cm$

The following 3 questions concern the same physical situation:

Consider a large tank with a closed pipe connected to its bottom as shown. The tank is filled to a height $H = 1$ m above the end of the pipe C. The cross sectional area of the pipe is $A = 0.01\ \text{m}^2$. The fluid has a density of $\rho_f = 1\text{g/cm}^3$.

Now the pipe is suddenly opened at point C and the oil squirts up into the air making a fountain. Assume that oil level H is kept constant by continuously adding oil to the tank. Ignore the possibility that the fluid in the fountain might fall back down upon itself.



7. What is the volume flow rate (cubic meters per second) of the fluid at point C?

a. $20.3\times10^{-2}\ \text{m}^3/\text{s}$
b. $7.83\times10^{-2}\ \text{m}^3/\text{s}$
(c.) $4.43\times10^{-2}\ \text{m}^3/\text{s}$
d. $0.23\times10^{-2}\ \text{m}^3/\text{s}$
e. $1.23\times10^{-2}\ \text{m}^3/\text{s}$

$= P_{atm}$, $V_o \approx 0$, $= P_{atm}$

$$P_o + \frac{1}{2}\rho V_o^2 + \rho g H = P_c + \frac{1}{2}\rho V_c^2$$

$$\rho g H = \frac{1}{2}\rho V_c^2 \Rightarrow V_c = \sqrt{2gH}$$

$$\text{Flow rate} = V_c \times A = \sqrt{2gH}\,A = \sqrt{2\cdot 9.8\ \text{m/s}^2 \times 1\text{m}} \times 0.01\text{m}^2 = 0.0443\ \frac{\text{m}^3}{\text{s}}$$

8. The fluid in the fountain will rise to some maximum height h_{max}. How high above point C is h_{max}?

Energy conservation

a. ½ m
b. 3 m
c. 0 m
d. ¼ m
(e.) 1 m

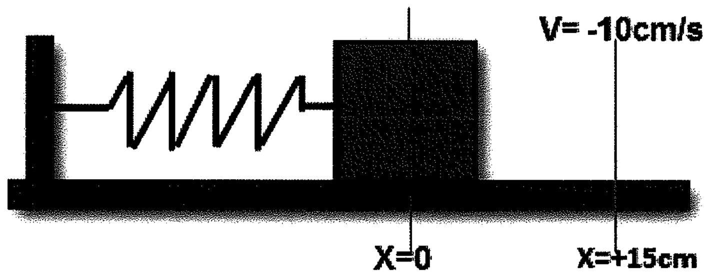
9. Suppose the fluid is replaced with a different one that has twice the density. How will the answers to the two previous questions change?

(a.) Neither one changes.
b. The flow rate and the maximum height both double.
c. The flow rate doubles and the maximum height is increased by a factor of four.
d. The flow rate and the maximum height are both halved.
e. The flow rate is halved and the maximum height is quartered.

See problem 7. – ρ cancels out

The following 4 questions concern the same physical situation:

A simple harmonic oscillator (a mass attached to a spring on a horizontal frictionless surface) has an angular frequency of $\pi/3$ radians per second. The mass is 100.0 g. The mass is started off with a position extended from the equilibrium position at x = 0 by +15.00 cm and an inward velocity of -10.00 cm/s.



10. What is the distance of the mass from the equilibrium position 10 s after it is started?

$x = A\cos(\omega t + \phi)$ (A from problem 12.) First find ϕ using info at t=0

a. 1.0000 m
b. -1.0000 m
c. 0.0016 m
d. 1.5000 m
(e.) 0.0077 m

$x = 0.15\text{ m} = 0.178\text{ m}\cos\phi \Rightarrow \cos\phi = \frac{0.15}{0.178} \Rightarrow \phi = 0.568$ rad

Now find x at t = 10 s:

$x = 0.178\text{ m} \times \cos\left(\frac{\pi}{3} 10\text{ s} + 0.568\right) = 0.0079\text{ m}$

11. What is the spring constant, *k*?

a. 9.87 N/m
b. 1.05 N/m
c. 0.02 N/m
(d.) 0.11 N/m
e. 0.33 N/m

$\omega = \sqrt{\frac{k}{m}} \Rightarrow k = m\omega^2 = 0.1\text{ kg} \times \left(\frac{\pi}{3}\right)^2 \frac{1}{s^2}$

$= 0.1096\text{ N}$

12. What is the amplitude of the oscillator?

a. 0.150 m
(b.) 0.178 m
c. 0.250 m
d. 0.335 m
e. 1.047 m

$\frac{1}{2}kA^2 = \frac{1}{2}mv^2 + \frac{1}{2}kx^2$

$A = \sqrt{\frac{m}{k}v^2 + x^2} = \sqrt{\frac{0.1\text{ kg}}{0.11\text{ N/m}}(10\text{ cm/s})^2 + (15\text{ cm})^2}$

$= 17.8\text{ cm} = 0.178\text{ m}$

13. What is the acceleration of the mass just after it was started at x = + 15 cm?

a. 2 m/s^2
b. 0.16 m/s^2
(c.) -0.16 m/s^2
d. -3 m/s^2
e. 3 m/s^2

$F = ma$, $F = -kx$

$\Rightarrow a = -\frac{k}{m}x = -\frac{0.11\text{ N/m}}{0.1\text{ kg}} 0.15\text{ m} = -0.165\text{ m/s}^2$

14. The total energy of a simple harmonic oscillator (a mass on a spring on a horizontal frictionless surface with similar layout to question 13) is 0.05 J. Its amplitude is 0.10 m. The mass is 2.50 kg. What is the angular frequency ω of the oscillator?

a. 1.0 radian/s
(b) 2.0 radians/s
c. 3.0 radians/s
d. 4.0 radians/s
e. 5.0 radians/s

$U = \frac{1}{2} k A^2$, $k = m\omega^2$ $\Rightarrow U = \frac{1}{2} m\omega^2 A^2 \Rightarrow \omega = \sqrt{\frac{2U}{mA^2}}$

$= \sqrt{\frac{2 \times 0.05 J}{2.5 kg \times (0.1 m)^2}} = 2$ rad/sec

15. A pendulum clock has a pendulum length l that is exactly 25 cm. The clock is found not to keep correct time. For instance, when 100.00 minutes pass the clock indicates that 98.79 minutes have passed. To what length l should the pendulum be adjusted so that the clock keeps correct time?

→ a. 24.4 cm
b. 24.7 cm
c. 25.0 cm
d. 25.3 cm
(e) 25.6 cm

$T = \frac{2\pi}{\omega} = 2\pi \sqrt{\frac{L}{g}}$

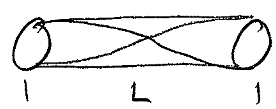
$\frac{T'}{T} = \sqrt{\frac{L'}{L}} \Rightarrow L' = L\left(\frac{T'}{T}\right)^2 = 25 \text{ cm} \left(\frac{98.79}{100}\right)^2 = 24.4 \text{ cm}$

16. A pipe organ with length 5.2 m is open at both ends. What is its fundamental frequency (corresponding to the longest possible wavelength)? The speed of sound in air is 343 m/s.

(a) 33.0 Hz
b. 107.2 Hz
c. 214.4 Hz

$v = \lambda f \Rightarrow f = \frac{v}{\lambda} = \frac{v}{2L}$

$= \frac{343 \text{ m/s}}{2 \times 5.2 \text{ m}} = 33 \text{ 1/s}$



$\lambda = 2L$

The following 2 questions concern the same physical situation:

Standing 10 meters from a stopped ambulance, you notice the siren's pitch is 500 Hz. Another day, while standing by the side of a road, you see the same ambulence driving and hear the siren but its pitch is 520 Hz. (Speed of sound in air is 340 m/s)

17. What is the speed of the ambulance?

a. 17 m/s
b. 15 m/s
(c) 13 m/s

$f_o = f_s \times \frac{(V_{sound} \pm V_o)}{(V_{sound} - V_s)}$ $\quad V_o = 0$

$V_{sound} f_o - V_s f_o = V_{sound} f_s \Rightarrow V_s = V_{sound} \frac{f_o - f_s}{f_o}$

$= 340 \text{ m/s} \frac{520 - 500}{520}$

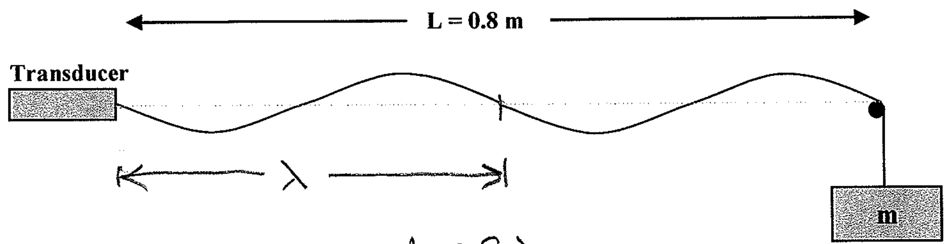
$= 13 \text{ m/s}$

18. What direction is the ambulance going?

(a) Toward you.
b. Away from you.

The next 3 questions pertain to the same situation:

A string is stretched between a transducer and a support. It is held in tension by a mass hanging off one end. The length of the string $L = 0.8$ m and its mass density $\mu = 0.1$ kg/m. The transducer excites a standing wave on the string as shown in the figure. The speed of sound waves on the string is determined to be $v = 32$ m/s.



$L = 2\lambda$

19. Is this wave transverse or longitudinal?

(a.) transverse
b. longitudinal

20. What is the mass of the weight, m?

a. 4.5 kg
(b.) 10.4 kg
c. 24.0 kg
d. 36.5 kg
e. 44.2 kg

$$\left.\begin{array}{l} T = mg \\ v = \sqrt{\frac{T}{\mu}} \end{array}\right\} \rightarrow m = \frac{\mu v^2}{g} = \frac{0.1\ \text{kg/m} \times (32\ \text{m/s})^2}{9.8\ \text{m/s}^2} = 10.4\ \text{kg}$$

21. What is the frequency of the oscillation of the string, f?

a. 55 Hz
b. 63 Hz
(c.) 80 Hz
d. 92 Hz
e. 105 Hz

$$v = \lambda f \rightarrow f = \frac{v}{\lambda} = \frac{v}{L/2} = \frac{32\ \text{m/s}}{0.8\ \text{m}/2} = 80\ 1/\text{s}$$

The next 2 questions pertain to the same physical situation:

You are trying to study but your roommate is blasting his stereo so loud you cannot think. You are standing a distance 2 m away and measure the intensity of the sound to be $I = 5.7\ \text{W/m}^2$.

22. What is the loudness of the sound?

a. 105 dB
b. 112 dB
c. 119 dB
(d.) 128 dB
e. 131 dB

$$\beta = 10\ \text{dB} \log_{10} \frac{5.7}{10^{-12}} = 127.6\ \text{dB}$$

23. You cannot study if the intensity is greater than 0.5 W/m^2. What is the minimum distance to which you must move from the stereo? (Assume there are no obstacles you can hide behind and you have no ear plugs.)

a. 3.86 m
(b.) 6.75 m
c. 6.69 m
d. 12.8 m
e. 25.4 m

$$I = \frac{P}{4\pi r^2}$$

$$\frac{I'}{I} = \frac{r^2}{r'^2} \Rightarrow r' = r\sqrt{\frac{I}{I'}} = 2m\sqrt{\frac{5.7}{0.5}} = 6.75 \text{ m}$$

24. Two identical sirens are placed 10 meters away from you. From them you hear a sound of loudness β_0. How many sirens the same as these two sirens should be placed 20 m away from you to produce the sound of the same loudness β_0?

a. 6
b. 5
c. 7
d. 4
(e.) 8

$$I = \frac{P}{4\pi r^2}$$

Double $r \Rightarrow I \rightarrow \frac{1}{4} I$ So need 4×2 sirens = 8 sirens

Physics 101 Formulas

Kinematics

$\mathbf{v}_{ave} = \Delta\mathbf{x}/\Delta t$ $\quad \mathbf{a}_{ave} = \Delta\mathbf{v}/\Delta t$

$v = v_0 + at$ $\quad x = x_0 + v_0 t + \frac{1}{2}at^2$ $\quad v^2 = v_0^2 + 2a\Delta x$

$g = 9.8 m/s^2 = 32.2 ft/s^2$ (near Earth's surface)

Dynamics

$\Sigma\mathbf{F} = m\mathbf{a}$ $\quad F_g = Gm_1m_2 / R^2$ $\quad F_g = mg$ (near Earth's surface)

$f_{s,max} = \mu_s F_N$ $\quad$ Gravitational constant, $G = 6.7 \times 10^{-11}\ N{\cdot}m^2/kg^2$

$f_k = \mu_k F_N$ $\quad a_c = v^2 / R = \omega^2 R$

Work & Energy

$W_F = FS\cos(\theta)$ $\quad K(\text{or } KE) = \frac{1}{2}mv^2$ $\quad W_{NET} = \Delta K = K_f - K_i$ $\quad E = K + U$

$W_{nc} = \Delta E = E_f - E_i = (K_f + U_f) - (K_i + U_i)$

$W_{grav} = -mg\Delta y$ $\quad U_{grav}$ (or PE_{grav}) $= mgy$

Impulse & Momentum

Impulse $\mathbf{I} = \mathbf{F}_{ave}\Delta t = \Delta\mathbf{p}$ $\quad \mathbf{F}_{ave}\Delta t = \Delta\mathbf{p} = m\mathbf{v}_f - m\mathbf{v}_i$ $\quad \mathbf{F}_{ave} = \Delta\mathbf{p}/\Delta t$

$\Sigma\mathbf{F}_{ext}\Delta t = \Delta\mathbf{P}_{total} = \mathbf{P}_{total,final} - \mathbf{P}_{total,initial}$ (momentum conserved if $\Sigma\mathbf{F}_{ext} = 0$)

$\mathbf{X}_{cm} = (m_1\mathbf{x}_1 + m_2\mathbf{x}_2)/(m_1 + m_2)$

Rotational Kinematics

$\omega = \omega_0 + \alpha t$ $\quad \theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$ $\quad \omega^2 = \omega_0^2 + 2\alpha\Delta\theta$

$\Delta x_T = \Delta\theta R$ $\quad v_T = \omega R$ $\quad a_T = \alpha R$ (rolling without slipping: $\Delta x = \Delta\theta R$ $\quad v = \omega R$ $\quad a = \alpha R$)

Rotational Statics & Dynamics

$\tau = Fr\sin\theta$

$\Sigma\tau = 0$ and $\Sigma F = 0$ (static equilibrium)

$\Sigma\tau = I\alpha$

$I = \Sigma mr^2$ (for a collection of point particles)

$I = \frac{1}{2}MR^2$ (solid disk or cylinder) $\quad I = \frac{2}{5}MR^2$ (solid sphere) $\quad I = \frac{2}{3}MR^2$ (hollow sphere)

$I = MR^2$ (hoop or hollow cylinder) $\quad I = \frac{1}{12}ML^2$ (uniform rod about center)

$W = \tau\theta$ (work done by a torque)

$\mathbf{L} = I\omega$ $\quad \Sigma\tau_{ext}\Delta t = \Delta\mathbf{L}$ (angular momentum conserved if $\Sigma\tau_{ext} = 0$)

$K_{rot} = \frac{1}{2}I\omega^2 = L^2/2I$ $\quad K_{total} = K_{trans} + K_{rot} = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$

Simple Harmonic Motion

Hooke's Law: $F_s = -kx$

$W_{spring} = \frac{1}{2}kx_i^2 - \frac{1}{2}kx_f^2$ $\quad U_{spring} = \frac{1}{2}kx^2$

$x(t) = A\cos(\omega t)$ or $x(t) = A\sin(\omega t)$ or $x(t) = x_0\cos(\omega t) + (v_0/\omega)\sin(\omega t)$

$v(t) = -A\omega\sin(\omega t)$ or $v(t) = A\omega\cos(\omega t)$ or $v(t) = -x_0\omega\sin(\omega t) + v_0\cos(\omega t)$

$a(t) = -A\omega^2\cos(\omega t)$ or $a(t) = -A\omega^2\sin(\omega t)$ or $a(t) = -x_0\omega^2\cos(\omega t) - v_0\omega\sin(\omega t)$

$a(t) = -\omega^2 x(t)$

$\omega^2 = k/m$ $\quad T = 2\pi/\omega = 2\pi\sqrt{m/k}$ $\quad f = 1/T$ $\quad A^2 = x^2 + (v/\omega)^2$

$x_{max} = A$ $\quad v_{max} = \omega A$ $\quad a_{max} = \omega^2 A$ $\quad \omega = 2\pi f$

For a simple pendulum $\omega^2 = g/L$, $T = 2\pi\sqrt{L/g}$

Fluids
$P = F/A$, $P(d) = P(0) + \rho g d$ change in pressure with depth d
Buoyant force $F_B = \rho g V_{dis}$ = weight of displaced fluid
Flow rate $Q = v_1 A_1 = v_2 A_2$ continuity equation (area of circle $A = \pi r^2$)
$P_1 + {}^1/_2\rho v_1^2 + \rho g y_1 = P_2 + {}^1/_2\rho v_2^2 + \rho g y_2$ Bernoulli equation
$\rho_{water} = 1000\ kg/m^3$ $1 m^3 = 1000$ liters
$\rho = M/V$ 1 atmos. $= 1.01 \times 10^5$ Pa 1 Pa = 1 N/m²

Temperature and Heat
Temperature: Celsius (T_C) to Fahrenheit (T_F) conversion: $T_C = (5/9)(T_F - 32)$
Celsius (T_C) to Kelvin (T_K) conversion: $T_K = T_C + 273$
$\Delta L = \alpha L_0 \Delta T$ $\Delta V = \beta V_0 \Delta T$ thermal expansion
$Q = cM\Delta T$ specific heat capacity
$Q = L_f M$ latent heat of fusion (solid to liquid) $Q = L_v M$ latent heat of vaporization
$Q = kA\Delta Tt/L$ conduction
$Q = e\sigma T^4 At$ radiation ($\sigma = 5.67\times10^{-8}\ J/(s\cdot m^2\cdot K^4)$)
$P_{net} = e\sigma A(T^4 - T_0^4)$ (surface area of a sphere $A = 4\pi r^2$)

Ideal Gas & Kinetic Theory
$N_A = 6.022 \times 10^{23}$ molecules/mole Mass of carbon-12 = 12.000u
$PV = nRT = Nk_BT$ $R = 8.31\ J/(mol\cdot K)$ $k_B = R/N_A = 1.38 \times 10^{-23}\ J/K$
$KE_{ave} = {}^3/_2 k_BT = {}^1/_2 mv_{rms}^2$ $U = {}^3/_2 Nk_BT$ (internal energy of a monatomic ideal gas)
$v_{rms}^2 = 3k_BT/m = 3RT/M$ (M = molar mass = kg/mole)

Thermodynamics
$\Delta U = Q + W$ (1'st law)

$U = ({}^3/_2)nRT$ (internal energy of a monatomic ideal gas for fixed n)

$C_V = ({}^3/_2)R = 12.5\ J/(mol\cdot K)$ (specific heat at constant volume for a monatomic ideal gas)

$Q_H = Q_C + W$ (heat engine or refrigerator)
$e = W/Q_H = 1 - Q_C/Q_H$ $e_{max} = 1 - T_C/T_H$ (Carnot engine)
$Q_C/Q_H = T_C/T_H$ at maximum efficiency (2'nd law)
$W = -P\Delta V$ (work done by expanding gas)

Harmonic Waves
$v = \lambda / T = \lambda f$
$v^2 = F/(m/L)$ for wave on a string
$v = c = 3 \times 10^8$ m/s for electromagnetic waves (light, microwaves, etc.)
$I = P/(4\pi r^2)$ (sound intensity)

Sound Waves
Loudness: $\beta = 10 \log_{10}(I/I_0)$ (in dB), where $I_0 = 10^{-12}\ W/m^2$

$$f_{observer} = f_{source}\frac{v_{wave} - v_{observer}}{v_{wave} - v_{source}}$$ (Doppler Effect)