The equation sheets may be removed when the test begins

**Guidelines:**
- Assume 3 significant figures for all given numbers unless otherwise stated
- Show all of your work – no work, no credit
- Write your final answer in the box provided - include units for all answers
- If you finish with less than 5 minutes remaining, remain seated until the end of the exam and all exams are collected.

### Uniform Circular Motion

- \( a_n \) – centripetal acceleration
- \( v \) – speed
- \( r \) – radius of curvature
- \( \omega \) – rotational speed
- \( T \) – period
- \( f \) – frequency
- \( \phi \) – angle

\[
\begin{align*}
a_n &= \frac{v^2}{r} \quad \text{(any curve)} \\
a_n &= r\omega^2 \\
v &= \omega r \\
T &= \frac{2\pi}{\omega} \\
f &= \frac{1}{T} \\
\Delta s &= r\Delta\phi \\
\omega &= 2\pi f
\end{align*}
\]

### Universal Law of Gravitation

\[
F_G = G \frac{m_1 m_2}{r^2}
\]

\( G = 6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2 \)

### Kepler’s Third Law

\[
T^2 = \left(\frac{2\pi}{\omega}\right)^2 a^3
\]

\[
\frac{1}{GM}
\]

### Density of Water

- 62.4 lb/ft\(^3\)
- 1000 kg/m\(^3\)

### Atmospheric Pressure

- 1 atm = 101.3 kPa
- 1 atm = 14.7 psi

### Conversions

- 1 ft\(^3\) = 7.48 gal
- 1 m\(^3\) = 1000 L

### Stokes’ Law

Sphere through fluid for laminar flow

\[
F_{\text{drag}} = 6\pi \eta R v
\]

### Poiseuille’s Equation

\[
Q = \frac{\pi r^4 (P_1 - P_2)}{8\eta L}
\]

\( \eta \) – viscosity
\( L \) – characteristic length
\( v \) – velocity
\( \rho \) – mass density
\( R \) – sphere radius
### Harmonic Motion
\( \omega \) – angular frequency  
\( A \) – amplitude  
\( k \) – stiffness  
\( m \) – mass  
\( \delta \) – phase angle  
\( x_0 \) – initial displacement  
\( v_0 \) – initial velocity  
\( T \) – period  
\( f \) – frequency

\[
x(t) = A \sin(\omega t + \delta) \\
= a_1 \sin(\omega t) + a_2 \cos(\omega t) \\
v(t) = A \omega \cos(\omega t + \delta) \\
= a_1 \omega \cos(\omega t) - a_2 \omega \sin(\omega t) \\
a(t) = -A \omega^2 \sin(\omega t + \delta) \\
= -a_1 \omega^2 \sin(\omega t) - a_2 \omega^2 \cos(\omega t) \\
\omega = \sqrt{\frac{k}{m}} \\
A = \sqrt{a_1^2 + a_2^2} \\
\delta = \tan^{-1}\left(\frac{a_2}{a_1}\right) \\
a_1 = \frac{v_0}{\omega} \\
a_2 = x_0 \\
T = \frac{2\pi}{\omega} \\
\omega = 2\pi f
\]

### Wave Equation
\( v \) – wave velocity  
\( A \) – amplitude  
\( k \) – wave number  
\( \omega \) – angular frequency  
\( \lambda \) – wavelength  
\( T \) – frequency  
\( z(x,t) = A \sin(kx - \omega t) \)

\[
v = \lambda f \\
k = \frac{2\pi}{\lambda} \\
v \text{ is positive if sign of } \omega \text{ is negative}
\]

### Parallel Axis Theorem
\[
I = I_{cm} + Mr^2
\]

### Pendulums
Simple: \( \omega = \sqrt{\frac{g}{l}} \)
Physical: \( \omega = \sqrt{\frac{Mg}{I}} \)

### Speed of Sound in Air
\( v \approx (331 + 0.60T) \text{m/s} \)  
\( T \) in °C

### Beat Frequency:
\[
|t_2 - t_1|
\]

### Natural Frequencies:
\( \lambda \) – wavelength  
\( L \) – Length  
\( n \) – harmonic  
\( T \) – tension  
\( \mu \) – mass per unit length  
\( f \) – frequency  
\( v \) – wave velocity in medium

### String
\[
\lambda_n = \frac{2L}{n} \\
f_n = \frac{v}{\lambda_n} = \frac{n}{2L\sqrt{\mu}} \\
\text{closed pipe: } \lambda_n = \frac{4L}{n} \text{ for } n = 1, 3, 5… \\
\text{open pipe: } \lambda_n = \frac{2L}{n} \text{ for } n = 1, 2, 3…
\]

### Air Columns
\( \text{closed pipe: } \lambda_n = \frac{4L}{n} \text{ for } n = 1, 3, 5… \\
\text{open pipe: } \lambda_n = \frac{2L}{n} \text{ for } n = 1, 2, 3…
\]

### Wave Speed
\( C \) – speed of sound  
\( v \) – wave velocity  
\( T \) – tension  
\( \mu \) – mass per unit length  
\( E \) – modulus of elasticity  
\( \rho \) – mass density

\[
\text{Transverse: } v = \sqrt{\frac{T}{\mu}} \\
\text{Longitudinal: } v = \sqrt{\frac{E}{\rho}}
\]

### Sound Level
\( I_0 \) – reference intensity, \( 1 \times 10^{-12} \text{W/m}^2 \)  
\( I \) – intensity  
\( \beta \) (in dB) = \( 10 \log \frac{I}{I_0} \)

### Doppler Shift
\( f_0 \) – frequency  
\( f' \) – shifted frequency  
\( v \) – velocity of medium  
\( v_S \) – velocity of source  
\( v_L \) – velocity of listener  
\( f' = f_0 \frac{v + v_L}{v + v_S} \)

Positive is from listener to source.

### Wave Energy, Power, Intensity
\( E \) – energy  
\( I \) – intensity  
\( P \) – power

\[
\bar{P} = \frac{\langle P \rangle}{2\pi} = 2\pi \mu f^2 A^2 \\
P = 4\pi^2 \mu f^2 A^2 \cos^2 (kx - \omega t) \\
I = \frac{\bar{P}}{4\pi^2} = \frac{I_2}{I_1} = \frac{1}{r_L^2} \\
\]

### Light Waves
\( \theta_r = \theta_a \)

### Law of Reflection
\( n = \frac{c}{v} \)

### Index of Refraction
\( \theta_a \) sin \( \theta_a = n_b \) sin \( \theta_b \)

### Law of Refraction
\( n_a \) sin \( \theta_a = n_b \) sin \( \theta_b \)

### Light Wavelength
\[
\lambda = \frac{\lambda_0}{n} \\
\text{Total Internal Reflection} \\
\sin \theta_{\text{crit}} = \frac{n_b}{n_a}
\]
### Thermal Expansion

**Linear**
\[ \Delta l = \alpha_0 \Delta T \]

**Linear, Stresses**
\[ \sigma = \alpha E \Delta T \]

**Volumetric**
\[ \Delta V = \beta V_0 \Delta T \]

### Ideal Gas Law

\[ pV = nRT \]

\( R = 8.314 \text{ J/(mol-K)} \)

Avogadro’s Number: \( 6.02 \times 10^{23} \)

Standard Pressure and Temp
\( 273K \ 1.00 \text{ atm (101.3kPa)} \)

### 1st Law of Thermodynamics

**U** – internal energy

**W** – work done by thermal system

**Q** – heat flow into thermal system

\[ \Delta U = -W_{A \rightarrow B} + Q_{A \rightarrow B} \]

### Molecular Thermal Physics

\( m \) – mass of a molecule

\( M \) – molecular mass

\( n \) – number of moles

\( N \) – number of molecules

\( k \) – Boltzmann constant = \( 1.38065 \times 10^{-23} \text{ J/K} \)

\[ U = N \left( \frac{1}{2} m \langle v^2 \rangle \right) \]

\[ U = \frac{3}{2} nRT \]

\[ v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3kT}{m}} \]

### Work of Thermal Systems

**Isobaric (constant pressure)**
\[ W = \int p dV \]

**Isotonic (constant volume)**
\[ W = P(V_B - V_A) \]

**Isothermal (constant temp)**
\[ W = nRT \ln \left( \frac{V_2}{V_1} \right) \]

\[ \Delta Q = W \]

**Adiabatic (\( \Delta Q = 0 \))**
\[ W = \frac{1}{\gamma - 1} \left( p_A V_A - p_B V_B \right) \]

### Efficiency

**General**
\[ \eta = \frac{W}{Q_h} = 1 - \frac{|Q_c|}{Q_h} \]

**Otto Cycle**
\[ r = \text{compression ratio} \]

\[ \eta = 1 - \frac{1}{r^{\gamma - 1}} \]

**Carnot Cycle**
\[ \eta = 1 - \frac{T_c}{T_h} \]

\[ \frac{Q_c}{Q_h} = \frac{T_c}{T_h} \]

### Heat

**Q** – heat

\( c \) – specific heat

\( \kappa \) – thermal conductivity

\( R \) – thermal resistance

### Heat Capacity

\[ Q = mc \Delta T \]

### Thermal Conductivity

\[ \Delta Q = -k \alpha T_2 - T_1 = -A \frac{T_2 - T_1}{R} \]

### Thermal Resistance

\[ R = L \kappa \]

### Thermal Resistance, Series

\[ R_{eff} = R_1 + R_2 \]

### Thermal Resistance, Parallel

\[ \frac{1}{R_{eff}} = \frac{1}{A_1} + \frac{1}{A_2} \left( \frac{A_1 + A_2}{R_1 + R_2} \right) \]

### Refrigerators

**General**
\[ K = \text{coefficient of performance} \]

\( H \) – heat current

\( P \) – power input

\[ |Q_h| = W + |Q_c| \]

\[ K = \frac{|Q_h|}{|W|} = \frac{H}{P} \]

**Carnot**
\[ K_{Carnot} = \frac{T_c}{T_h - T_c} \]

### Water Properties

\( c = 1 \text{ cal/(g·°C)} = 4.186 \text{ J/(g·°C)} \)

\( L_f = 79.6 \text{ cal/g} \)

\( L_v = 540 \text{ cal/g} \)

\( \rho = 1 \text{ g/cm}^3 = 1 \text{ kg/L} \)

\[ = 1000 \text{ kg/m}^3 = 62.4 \text{ lb/ft}^3 \]

\( L_f = \text{Latent heat of fusion} \)

\( L_v = \text{Latent heat of vaporization} \)
Constants
\( m_e = 9.109 \times 10^{-31} \text{ kg} \)
\( m_p = 1.673 \times 10^{-27} \text{ kg} \)
\( m_n = 1.675 \times 10^{-27} \text{ kg} \)

\( k = 9 \times 10^9 \text{ Nm}^2 \text{ C}^{-2} \)

\( \varepsilon_0 = 8.854 \times 10^{-12} \text{ C}^2 \text{ Nm}^{-2} \text{ or } \frac{F}{m} \)

\( e = -1.6022 \times 10^{-19} \text{ C} \) (electron charge)
\( eV = 1.6022 \times 10^{-19} \text{ J} \) (electron volt)

Coulomb’s Law (electrostatic force)

\[ F = k \left| \frac{q_1 q_2}{r^2} \right| \]

\[ F = \frac{1}{4\pi \varepsilon_0} \left| \frac{q_1 q_2}{r^2} \right| \]

Electric Field – point charge

\[ \vec{E} = \frac{\vec{F}}{q} = \frac{1}{4\pi \varepsilon_0 \ r^2} \vec{r} \]

Potential energy - point charges

\[ U = \frac{1}{4\pi \varepsilon_0} \sum_{i,j} \frac{q_i q_j}{r_{ij}} \]

Potential

\[ V = \frac{U}{q_0} \]

Potential of a set of point charges

\[ V = \frac{1}{4\pi \varepsilon_0} \sum_i \frac{q_i}{r_i} \]

Potential difference between two parallel plates

\[ V_u - V_b = Ed \]

Electric Flux

\( \Phi_E = \oint \vec{E} \cdot d\vec{A} = \frac{Q_{encl}}{\varepsilon_0} \)

Capacitance

\[ C = \frac{Q}{V_{ab}} \quad 1 \text{ F} = \frac{1 \text{ C}}{1 \text{ V}} \]

Capacitance – parallel plates

\[ C = \frac{\varepsilon_0 A}{d} \quad \text{in a vacuum} \]

Capacitance – energy storage

\[ U = \frac{1}{2} \frac{Q^2}{C} = \frac{1}{2} \frac{C V^2}{2} = \frac{1}{2} QV \]

Capacitors in series

\[ \frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots \]

Capacitors in parallel

\[ C_{eq} = C_1 + C_2 + C_3 + \ldots \]

Resistors in series

\[ R_{eq} = R_1 + R_2 + R_3 + \ldots \]

Resistors in parallel

\[ \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots \]

Current

\[ I = \frac{dQ}{dt} \quad 1 \text{ A} = \frac{1 \text{ C}}{1 \text{ sec}} \]

Voltage, Resistance, Current, Power

\[ V = l \cdot R \quad P = l \cdot V \quad R = \frac{\rho L}{A} \]

Kirchhoff’s Rules

\[ \sum V = 0 \quad \text{for a closed loop} \]
\[ \sum I = 0 \quad \text{for a junction} \]

Magnetism

\[ 1 \text{T} = \frac{1 \text{Vs}}{\text{m}^2} = \frac{1}{\text{A} \cdot \text{m}} = 10000 \text{ gauss} \]
\[ \mu_0 = 4\pi \times 10^{-7} \text{ T} \cdot \text{m} \]

Magnetic force on moving charged particle

\( \vec{F} = q(\vec{v} \times \vec{B}) \)

Magnetic field of a moving charged particle

\[ \vec{B} = \frac{\mu_0 q \vec{v} \times \vec{r}}{4\pi r^2} \]

Magnetic Field of a straight wire

\[ B = \frac{\mu_0 I}{2\pi r} \]

Magnetic field along the axis of a looped wire

\[ B_x = \frac{\mu_0 N I a^2}{2(x^2 + a^2)^{3/2}} \]

a – radius of the loop
x – distance from the center of the loop to point of interest on the axis.
I – current in the wires
N – number of loops

\[ P = \text{power} \quad V = \text{voltage} \]
\[ R = \text{resistance} \quad \sqrt{P \times R} \]
\[ I = \text{current} \quad V = \text{voltage} \]
\[ P = \text{power} \quad R = \text{resistance} \]

\[ \frac{I}{V} \quad \frac{P}{V^2} \quad \frac{R}{I^2} \]
\[ \frac{V}{I} \quad \frac{P}{V} \quad \frac{\sqrt{P \times R}}{I} \]
\[ \frac{P}{V} \quad \frac{I}{V} \]

\[ \frac{V}{I} \quad \frac{P}{V} \quad \frac{1}{I^2} \]

\[ \frac{P}{V} \quad \frac{I}{V} \]

\[ \frac{V}{I} \quad \frac{P}{V} \quad \frac{1}{I^2} \]
Remove the 2 equation sheets, leaving the exam questions stapled together.
CLEARLY PRINT the information below.

Name: ____________________________________________________ EF 152 Section: ____________

1. (1 pt) What formula would you use to determine the required size of a mild steel bolt to withstand an axial load of 600 kN if the steel has a ultimate strength of 200 MPa and the factor of safety is to be 4?
   a. \[
   \frac{200 \times 10^6 \text{Pa}}{4} = \frac{600 \times 10^3 \text{N}}{\pi r^2}
   \]
   b. \[
   \frac{200 \times 10^6 \text{Pa}}{600 \times 10^3 \text{N}} = \frac{\pi r^2}{4}
   \]
   c. \[
   \frac{200 \times 10^9 \text{Pa}}{600 \times 10^3 \text{N}} = 4 \pi r^2
   \]
   d. \[
   \frac{200 \times 10^6 \text{Pa}}{600 \times 10^3 \text{N}} = 4 \pi d
   \]

2. (1 pt) When two solid steel spheres of radius R are placed in contact the magnitude of the force they exert on each other is F. Two solid spheres of radius 3R made of this steel are placed in contact. Since the mass of each ball is 27 times larger, what is the magnitude of the gravitational force between them?
   a. 9 F
   b. 54 F
   c. 81 F
   d. 729 F

3. (1 pt) A ship goes from freshwater (\( \rho = 1000 \text{ kg/m}^3 \)) to salt water (\( \rho = 1029 \text{ kg/m}^3 \)). The ship will:
   a. Float lower in saltwater than freshwater
   b. Float higher in saltwater than freshwater
   c. Float at the same level in saltwater and freshwater

4. (1 pt) Two parallel springs of different spring constants but equal unstretched lengths are stretched due to a hanging weight. What is the same in each spring?
   a. Force
   b. Stress
   c. Strain

5. (7 pts) How far does Dr. Bennett have to walk down the 250 lb beam in order to tip the beam off of the support at A? Assume he weighs 150 lbs.
6. (7 pts) An object with a specific gravity of 0.75 and a volume of 0.80 ft$^3$ is pushed down and completely submerged in a pond. What is the magnitude of its acceleration when it is released?

7. (7 pts) Water exits a pump through a 0.034 m$^2$ pipe at a pressure of 800 kPa and a flow rate of 0.5 m$^3$/sec. The water is pumped up 10.0 m to a 0.20 m$^2$ pipe. What is the pressure in the 0.20 m$^2$ pipe (at point A)?
8. (1 pt) A particle oscillates in simple harmonic motion. At what point is the acceleration zero?
   a. Maximum positive displacement  
   b. Maximum negative displacement  
   c. At the neutral position

9. (1 pt) A tuning fork produces a 250 Hz tone. When struck and held near a vibrating B3 guitar string, 15 beats are counted in 5 seconds. What are the possible frequencies of the guitar string?
   a. 247 Hz and 253 Hz  
   b. 248 Hz and 252 Hz  
   c. 265 Hz and 235 Hz

10. (1 pt) Red light (650 nm) and yellow light (580 nm) travel in a vacuum. Which has a higher velocity?
    a. Red light  
    b. Yellow light  
    c. Both have same velocity

11. (1 pt) What condition is necessary for total internal reflection in this fiber optic material?

    a. The core has a higher index of refraction than the cladding  
    b. The core is less dense than the cladding  
    c. The core has a lower index of refraction than the cladding

12. (7 pt) One person singing “Grandma Got Run Over by a Reindeer” produces a sound level of 69 dB. Some people join in so that the new sound level is 85 dB. Assuming all people are singing at the same intensity, determine the total number of people singing.
13. (7 pt) A Martian oscillates a 1 kg geology hammer on Mars and determines the period of the motion is 6 seconds. The pivot point A is 8 cm from the center of gravity of the hammer. The mass moment of inertia of the hammer about its center of gravity is 0.264 kg-m$^2$. What is the gravity on Mars?

\[ \text{gravity on Mars} \]

14. (7 pt) The Christmas Tree bandit’s speedometer is broken. A police car in pursuit of the bandit is travelling at 100 mph and has a siren with a frequency of 500 Hz. As the police car approaches, the bandit hears a frequency of 510 Hz. Assume the speed of sound is 767 mph. How fast is the Christmas Tree bandit driving?

\[ \text{speed of the Christmas Tree bandit} \]
15. (1 pt) The Mythbusters are checking a claim that a heat engine acting between 300K and 550K is 30% efficient. Is this myth:
   a. Busted (not possible)
   b. Plausible (might be true)

16. (1 pt) In an internal combustion engine, heat is added at:
   c. Constant volume
   d. Constant temperature
   e. Constant Pressure

17. (1 pt) Heat is added to a system at constant volume. The work done is equal to:
   f. Q
   g. \(-Q\)
   h. 0
   i. U
   j. \(-U\)

18. (1 pt) Given your experience of what feels colder when you touch it, which of the following materials would have the highest thermal conductivity?
   k. A metal cooking pan
   l. An oven mitt
   m. A dish towel
   n. Has nothing to do with conductivity

19. (7 pts) A 65 watt refrigerator has a coefficient of performance of 3.2. The surface area of the refrigerator is 5.5 m² and can maintain a maximum temperature difference of 52 °C. What is the thickness of the insulation inside the refrigerator? (κ_refrig=0.021 W/mK).
20. (7 pts) Find the work done for one cycle of the heat engine shown. Assume air is used in the heat engine ($\gamma = 1.4$)

21. (7 pts) A 57 mF capacitor has stored energy from a potential difference of 243 Volts. What is the temperature change if the stored energy is used to heat 247 g of water?
22. (1 pt) Direct current produces a
   o. Changing magnetic field
   p. Constant magnetic field
   q. No magnetic field

23. (1 pt) All three resistors have the same resistance. Other than the resistance, what is the same for resistors R1 and R2?
   r. Voltage drop across resistor
   s. Current through the resistor
   t. Power dissipated by the resistor
   u. Nothing besides the resistance is the same for resistors R1 and R2

24. (1 pt) A capacitor is a device used to store:
   v. electric current
   w. electric potential
   x. electric charge
   y. magnetic energy

25. (1 pt) The electric field for a positive point charge:
   z. Acts away from the charge
   aa. Acts towards the charge
   bb. Is parallel to the charge
   cc. Is perpendicular to the charge

26. (7 pts) Write the loop equation for Loop 1 and the Junction equation for Junction A. You do not need to solve the system.

\[ L_1: \]
\[ J_a: \]
27. (7 pts) A proton with a velocity of \(7.3 \times 10^7 \text{ m/s}\) moves through a magnetic field of \(17 \hat{i} + 13 \hat{j} - 21 \hat{k}\) mT. What is the acceleration of the proton (magnitude and direction)?

28. (7 pts) Find the equivalent resistance of the circuit shown: