ALL QUESTIONS ARE WORTH 20 POINTS. WORK OUT FIVE PROBLEMS.

NOTE: Clearly write out solutions and answers (circle the answers) by section for each part (a., b., c., etc.)

Important Formulas:

1. **Motion along a straight line with a constant acceleration**
   
   \[ v_{\text{aver. speed}} = \frac{\text{[dist. taken]}}{\text{[time trav.]}} = \frac{S}{t}; \]
   \[ v_{\text{aver. vel.}} = \frac{\Delta x}{\Delta t}; \]
   \[ v_{\text{ins}} = \frac{dx}{dt}; \]
   \[ a_{\text{aver.}} = \frac{\Delta v_{\text{aver. vel.}}}{\Delta t}; \]
   \[ a = \frac{dv}{dt}; \]
   \[ v = v_0 + at; \quad x = \frac{1}{2}(v_0 + v)t; \]
   \[ v_{\text{aver. vel.}} = \frac{\Delta x}{\Delta t} = \frac{v}{t}; \]
   \[ v_{\text{ins}} = \frac{d}{d}x = \frac{1}{2}(v_0 + v); \]
   \[ v^2 = v_0^2 + 2ax \text{ (if } x_0=0 \text{ at } t_0=0) \]

2. **Free fall motion (with positive direction ↑)**
   
   \[ g = 9.80 \text{ m/s}^2; \]
   \[ y = v_{\text{aver.}} t; \]
   \[ v_{\text{aver.}} = \frac{(v + v_0)}{2}; \]
   \[ v = v_0 - gt; \quad y = v_0 t - \frac{1}{2} g t^2; \quad v^2 = v_0^2 - 2gy \text{ (if } y_0=0 \text{ at } t_0=0) \]

3. **Motion in a plane**
   
   \[ v_x = v_o \cos \theta; \]
   \[ v_y = v_o \sin \theta; \]
   \[ x = v_{ox} t + \frac{1}{2} a_x t^2; \quad y = v_{oy} t + \frac{1}{2} a_y t^2; \quad v_x = v_{ox} + at; \quad v_y = v_{oy} + at; \]

4. **Projectile motion (with positive direction ↑)**
   
   \[ v_x = v_{ox} = v_o \cos \theta; \]
   \[ x = v_{ox} t; \]
   \[ x_{\text{max}} = \frac{(2 v_o^2 \sin \theta \cos \theta)}{g} = \frac{(v_o^2 \sin2\theta)}{g} \text{ for } y_{\text{fin}} = y_{\text{in}}; \]
   \[ v_y = v_{oy} - gt = v_o \sin \theta - gt; \]
   \[ y = v_{oy} t - \frac{1}{2} gt^2; \]

5. **Uniform circular Motion**
   
   \[ a = v^2/r, \]
   \[ T = 2\pi/v \]

6. **Relative motion**
   
   \[ \vec{v}_{PA} = \vec{v}_{PB} + \vec{v}_{BA}; \]
   \[ \vec{a}_{PA} = \vec{a}_{PB}; \]

7. **Component method of vector addition**
\[ A = A_1 + A_2 ; \ A_x = A_{x1} + A_{x2} \text{ and } A_y = A_{y1} + A_{y2}; \quad A = \sqrt{A_x^2 + A_y^2}; \quad \theta = \tan^{-1} \left| \frac{A_y}{A_x} \right| \]

The scalar product \( \vec{A} \cdot \vec{B} = ab \cos \phi \)
\[ \vec{a} \cdot \vec{b} = (a_x \hat{i} + a_y \hat{j} + a_z \hat{k}) \cdot (b_x \hat{i} + b_y \hat{j} + b_z \hat{k}) \]
\[ \vec{a} \cdot \vec{b} = a_x b_x + a_y b_y + a_z b_z \]

The vector product \( \vec{a} \times \vec{b} = (a_x \hat{i} + a_y \hat{j} + a_z \hat{k}) \times (b_x \hat{i} + b_y \hat{j} + b_z \hat{k}) \)
\[ \vec{a} \times \vec{b} = -\vec{b} \times \vec{a} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ a_x & a_y & a_z \\ b_x & b_y & b_z \end{vmatrix} = \hat{i} \begin{vmatrix} a_y & a_z \\ b_y & b_z \end{vmatrix} - \hat{j} \begin{vmatrix} a_x & a_z \\ b_x & b_z \end{vmatrix} + \hat{k} \begin{vmatrix} a_x & a_y \\ b_x & b_y \end{vmatrix} = (a_y b_z - a_z b_y) \hat{i} + (a_x b_z - a_z b_x) \hat{j} + (a_x b_y - a_y b_x) \hat{k} \]

1. Second Newton’s Law \( ma = F_{net} ; \)
2. Kinetic friction \( f_k = \mu_k N ; \)
3. Static friction \( f_s = \mu_s N ; \)
4. Universal Law of Gravitation: \( F = GMm/r^2 ; \ G = 6.67 \times 10^{-11} \text{ Nm}^2/\text{kg}^2 ; \)
5. Drag coefficient \( D = \frac{1}{2} C \rho A v^2 \)
6. Terminal speed \( v_t = \sqrt{\frac{2 m g}{C \rho A}} \)
7. Centripetal force: \( F_c = m v^2 / r \)
8. Speed of the satellite in a circular orbit: \( v^2 = GM_0 / r \)
9. The work done by a constant force acting on an object: \( W = F d \cos \phi = \vec{F} \cdot \vec{d} \)
10. Kinetic energy: \( K = \frac{1}{2} m v^2 \)
11. Total mechanical energy: \( E = K + U \)
12. The work-energy theorem: \( W = K_f - K_0 ; \ W_{mc} = \Delta K + \Delta U = E_f - E_o \)
13. The principle of conservation of mechanical energy: when \( W_{mc} = 0, E_f = E_o \)
14. Work done by the gravitational force: \( W_g = m g d \cos \phi \)
1. Work done in Lifting and Lowering the object:
\[ \Delta K = K_f - K_i = W_a + W_g; \text{ if } K_f = K_i; \text{ } W_a = -W_g \]

2. Spring Force: \( F_s = -kx \) (Hooke's Law)

3. Work done by a spring force:
\[ W_s = \frac{1}{2} k x_i^2 - \frac{1}{2} k x_f^2; \text{ if } x_i = 0 \text{ and } x_f = x; \text{ } W_s = -\frac{1}{2} k x^2 \]

4. Work done by a variable force:
\[ W = \int_{x_i}^{x_f} F(x) \, dx \]

5. Power: \( P_{avg} = \frac{W}{\Delta t}; \text{ } P = \frac{dW}{dt}; \text{ } \bar{P} = F \cos \phi = \bar{F} \cdot \bar{v} \)

6. Potential energy: \( \Delta U = -W; \Delta U = -\int_{x_i}^{x_f} F(x) \, dx \)

7. Gravitational Potential Energy:
\[ \Delta U = m g (y_f - y_i) = m g \Delta y; \text{ if } y_i = 0 \text{ and } U_i = 0; \text{ } U(y) = m g y \]

8. Elastic potential energy:
\[ U(x) = \frac{1}{2} k x^2 \]

9. Potential energy curves:
\[ F(x) = -\frac{dU(x)}{dx}; \text{ } K(x) = E_{net} - U(x) \]

10. Work done on a system by an external force:
Friction is not involved \( W = \Delta E_{net} = \Delta K + \Delta U \)
When kinetic friction force acts within the system \( W = \Delta E_{net} + \Delta E_{ik} \)
\[ \Delta E_{ik} = \int f_k \, dt \]

11. Conservation of energy:
\[ W = \Delta E = \Delta E_{net} + \Delta E_{ik} + \Delta E_{int} \text{ for isolated system } (W = 0) \]
\[ \Delta E_{net} + \Delta E_{ik} + \Delta E_{int} = 0 \]

12. Power:
\[ P_{avg} = \frac{\Delta E}{\Delta t}; \text{ } P = \frac{dE}{dt}; \text{ } \bar{P} = M \bar{a}_{com} \]

13. Center of mass:
\[ \bar{r}_{com} = \frac{1}{M} \sum_{i=1}^{n} m_i \bar{r}_i \]

14. Newton's Second Law for a system of particles:
\[ \bar{F}_{net} = M \ddot{a}_{com} \]
1. **Linear Momentum and Newton’s Second law for a system of particles:**
   \[ \vec{p} = M \vec{v}_{com} \quad \text{and} \quad \vec{F}_{net} = \frac{d\vec{p}}{dt} \]

2. **Collision and impulse:**
   \[ \vec{j} = \int_{t_i}^{t_f} \vec{F}(t) \, dt; \quad J = F_{avg} \Delta t; \quad \text{when a stream of bodies with mass } m \text{ and speed } v \text{, collides with a body whose position is fixed} \]
   \[ F_{avg} = -\frac{n}{\Delta t} \Delta p = -\frac{n}{\Delta t} m \Delta v = -\frac{\Delta m}{\Delta t} \Delta v \]
   **Impulse-Linear Momentum Theorem:**
   \[ \vec{p}_f - \vec{p}_i = \vec{j} \]

3. **Law of Conservation of Linear momentum:**
   \[ \vec{p}_f = \vec{p}_f \quad \text{for closed, isolated system} \]

4. **Inelastic collision in one dimension:**
   \[ \vec{p}_{1f} + \vec{p}_{2i} = \vec{p}_{1f} + \vec{p}_{2f} \]

5. **Motion of the Center of Mass:**
   The center of mass of a closed, isolated system of two colliding bodies is not affected by a collision.

6. **Elastic Collision in One Dimension:**
   \[ v_{1f} = \frac{m_1 - m_2}{m_1 + m_2} v_{1i}; \quad v_{2f} = \frac{2 m_1}{m_1 + m_2} v_{1i} \]

7. **Collision in Two Dimensions:**
   \[ p_{1fx} + p_{2fx} = p_{1fx} + p_{2fx}; \quad p_{1fy} + p_{2fy} = p_{1fy} + p_{2fy} \]
   \[ R v_{rel} = M a \quad \text{(first rocket equation)} \]

8. **Variable-mass system:**
   \[ v_f - v_i = v_{rel} \ln \frac{M_f}{M_i} \quad \text{(second rocket equation)} \]

9. **Angular Position:**
   \[ \theta = \frac{S}{r} \quad \text{(radian measure)} \]

10. **Angular Displacement:**
   \[ \Delta \theta = \theta_2 - \theta_1 \quad \text{(positive for counterclockwise rotation)} \]

11. **Angular velocity and speed:**
    \[ \omega_{avg} = \frac{\Delta \theta}{\Delta t}; \quad \omega = \frac{d \theta}{dt} \quad \text{(positive for counterclockwise rotation)} \]

12. **Angular acceleration:**
    \[ \alpha_{avg} = \frac{\Delta \omega}{\Delta t}; \quad \alpha = \frac{d \omega}{dt} \]
\[ \omega = \omega_o + \alpha t \]
\[ \theta - \theta_o = \frac{1}{2} (\omega_o + \omega)t \]

1. **Angular acceleration:**
\[ \theta - \theta_o = \omega_o t + \frac{1}{2} \omega t^2 \]
\[ \omega^2 = \omega_o^2 + 2 \alpha (\theta - \theta_o) \]
\[ \theta - \theta_o = \omega t - \frac{1}{2} \omega t^2 \]

2. **Linear and angular variables related:**
\[ s = \theta r; \ v = \omega r; \ a_r = a \]
\[ a_r = \frac{v^2}{r} = \omega^2 r; \ T = \frac{2 \pi r}{v} = \frac{2 \pi}{\omega} \]

3. **Rotational Kinetic Energy and Rotational Inertia:**
\[ K = \frac{1}{2} I \omega^2; \ I = \sum m_i r_i^2 \] for body as a system of discrete particles;
\[ I = \int r^2 dm \] for a body with continuously distributed mass.

4. **The parallel axes theorem:**
\[ I = I_{com} + M h^2 \]

5. **Torque:**
\[ \tau = r F \sin \phi = r \perp F \]

6. **Newton's second law in angular form:**
\[ \tau_{net} = I \alpha \]

7. **Work and Rotational Kinetic Energy:**
\[ W = \int \tau d\theta; \ W = \tau (\theta_f - \theta_i) \] for \( \tau = \text{const} \);
\[ P = \frac{dW}{dt}; \ \Delta K = K_f - K_i = \frac{1}{2} I \omega_f^2 - \frac{1}{2} I \omega_i^2 = W \] work energy theorem for rotating bodies
\[ v_{com} = \omega R \]
\[ K = \frac{1}{2} I_{com} \omega^2 + \frac{1}{2} m v_{com}^2 \]

8. **Rolling bodies:**
\[ a_{com} = \alpha R \]
\[ a_{com} = \frac{g \sin \theta}{1 + I_{com}/M R^2} \] for rolling smoothly down the ramp

9. **Torque as a vector:**
\[ \vec{\tau} = \vec{r} \times \vec{F}; \ \tau = r F \sin \phi = r F \perp = r \perp F \]
1. Angular Momentum of a particle: 
\[ \vec{l} = \vec{r} \times \vec{p} = m (\vec{r} \times \vec{v}) ; \]
\[ l = r m v \sin \phi = r p_\perp = r m v_\perp = r_\perp p = r_\perp m v \]

2. Newton’s Second law in Angular Form: 
\[ \vec{r}_{net} = \frac{d\vec{l}}{dt} \]
\[ L = \sum_{i=1}^{n} \vec{l}_i \]

3. Angular momentum of a system of particles: 
\[ \vec{\tau}_{net} = \frac{d\vec{L}}{dt} \]

4. Angular Momentum of a Rigid Body: 
\[ \vec{L} = \vec{I} \omega \]

5. Conservation of Angular Momentum: 
\[ \vec{L}_i = \vec{L}_f \text{ (isolated system)} \]

6. Static equilibrium: 
\[ \vec{F}_{net} = 0; \ \vec{r}_{net} = 0 \]
if all the forces lie in xy plane \[ F_{v, i}, x = 0; F_{v, i}, y = 0; \ \tau_{x, i}, z = 0 \]

7. Elastic Moduli: \[ \text{stress} = \text{modulus} \times \text{strain} \]

8. Tension and Compression: 
\[ \frac{F}{A} = E \frac{\Delta L}{L}, E \text{ is the Young's modulus} \]

9. Shearing: 
\[ \frac{F}{A} = G \frac{\Delta L}{L}, G \text{ is the shear modulus} \]

10. Hydraulic Stress: 
\[ p = B \frac{\Delta V}{V}, B \text{ is the bulk modulus} \]

11. Simple harmonic motion: 
\[ x = x_0 \cos(\omega t + \phi); \ v = -\omega x_0 \sin(\omega t + \phi); \ a = -\omega^2 x_0 \cos(\omega t + \phi) \]

12. The Linear Oscillator: 
\[ \omega = \sqrt{\frac{k}{m}}, \ T = 2\pi \sqrt{\frac{m}{k}} \]
\[ T = 2\pi \sqrt{\frac{l}{k}}, \text{ torsion pendulum} \]

13. Pendulums: 
\[ T = 2\pi \sqrt{\frac{L}{g}}, \text{ simple pendulum} \]
\[ T = 2\pi \sqrt{\frac{l}{mgh}}, \text{ physical pendulum} \]
1. Damped Harmonic Motion: \( x(t) = x_a e^{-\frac{b}{2m}t} \cos(\omega't + \phi) \), \( \omega' = \sqrt{\frac{k}{m} - \frac{b^2}{4m^2}} \), \( E(t) = \frac{1}{2} kx_a^2 e^{-\frac{b}{2m}t} \)

2. Sinusoidal waves: \( y(x,t) = y_a \sin(kx - \omega t) \), \( k = \frac{2\pi}{\lambda} \), \( \frac{\omega}{2\pi} = f = \frac{1}{T} \), \( v = \frac{\omega}{k} = \frac{\lambda}{T} = \lambda f \)

3. Wave speed on stretched string: \( v = \sqrt{\frac{\tau}{\mu}} \)

4. Average power transmitted by a sinusoidal wave on a stretched string: \( P_{av} = \frac{1}{2} \mu v \omega^2 y_a^2 \)

5. Interference of waves: \( y'(x,t) = [2y_a \cos \frac{1}{2} \phi] \sin(kx - \omega t + \frac{1}{2} \phi) \)

6. Standing waves: \( y'(x,t) = [2y_a \sin(kx)] \cos \omega t \)

7. Resonance: \( f = \frac{v}{\lambda} = n \frac{v}{2L} \), for \( n = 1, 2, 3, \ldots \)

8. Sound waves: \( v = \sqrt{\frac{B}{\rho}} \)

9. Interference:
   \[ \phi = \frac{\Delta L}{\lambda} 2\pi = m (2\pi) \text{ for } m = 0, 1, 2, 3 \ldots, \text{ constructive interference} \]
   
   \[ \phi = \frac{\Delta L}{\lambda} 2\pi = (2m + 1)\pi \text{ for } m = 0, 1, 2, 3 \ldots, \text{ destructive interference} \]

10. Sound Intensity: \( I = \frac{P}{A} \), \( I = \frac{1}{2} \rho v \omega^2 s^2 \), \( I = \frac{P}{4\pi r^2} \)

11. Sound level in decibels: \( \beta = (10 \log_{10} \frac{I}{I_0}) \), \( I_0 = 10^{-12} W/m^2 \)

12. Standing wave patterns in pipes:
   \( f = \frac{v}{\lambda} = \frac{n v}{2L} \), for pipe opened from both ends
   \( f = \frac{v}{\lambda} = \frac{n v}{4L} \), for pipe closed at one end and opened at the other

13. Beats: \( f_{b,\text{ext}} = f_1 - f_2 \)
1. **The Doppler effect:** $f' = f\left(1 \pm \frac{v_R}{v_s}\right)$, $v_R$ the speed of the receiver; $v_s$ the speed of the sound; ($v_s = 331 \text{ m/s}$);  

   + for receiver approaching stationary emitter,  
   - for receiver moving away from the stationary emitter;  

   $$f' = f\left(\frac{1}{1 \mp \frac{v_E}{v_s}}\right),$$  
   $v_E$ the speed of the emitter, $v_s$ the speed of the sound,  

   - for emitter approaching stationary receiver,  
   + for emitter moving away from the stationary receiver;  

   $$f' = f\frac{v_s \pm v_R}{v_s \mp v_E}$$ general Doppler Effect
1. A 10 kg box is at rest at the end of unstretched spring with a constant \( k = 4000 \text{ N/m} \). The mass is struck with a hammer giving it a velocity of 6.0 m/s to the right across a frictionless surface. What is the amplitude of the resulting oscillations of this system?

\[ \begin{align*}
\text{1) Natural frequency of SHO} \\
&= \omega = \sqrt{\frac{k}{m}} = \sqrt{\frac{4000 \text{ N/m}}{10 \text{ kg}}} = 20 \text{ rad/s} \\
\text{2) After hammer strikes the mass} \\
&= \text{it will obtain a velocity maximum value} \\
&= v = \omega A \\
\text{3) } \Rightarrow \text{ requested} \\
&= A = \frac{v}{\omega} = \frac{v}{\sqrt{\frac{k}{m}}} \\
&= \frac{6.0 \text{ m/s}}{\sqrt{\frac{4000 \text{ N/m}}{10 \text{ kg}}}} = 3.0 \times 10^{-1} \text{ m}
\end{align*} \]
2. Your grandfather clock’s pendulum has a length of 0.9930 m. If the clock loses half a minute per day, how should you adjust the length of the pendulum?

For a simple pendulum $T = 2\pi \sqrt{\frac{L}{g}}$

Suppose clock's pendulum oscillates "n" times in a day.

\[ nT_1 = (24 \cdot 3600 - 30) = 86370s \]

after the adjustment of the pendulum's length

\[ nT_2 = (24 \cdot 3600) = 86400s \]

Take ratio

\[ \frac{T_2}{T_1} = \frac{2\pi \sqrt{\frac{L_2}{g}}}{2\pi \sqrt{\frac{L_1}{g}}} = \sqrt{\frac{L_2}{L_1}} = \frac{86400}{86370} \]

\[ \Rightarrow L_2 = \frac{86400^2 \cdot 0.9930}{86370^2} = 0.9937 \]

\[ \Rightarrow L_2 - L_1 = 0.9937 - 0.9930 = 7 \cdot 10^{-4} m \]
3. A transverse periodic wave on a string with a linear density of 0.200 kg/m is described by the following equation: \( y = 0.005 \sin (21.0x - 419t) \), where \( x \) and \( y \) are in meters and \( t \) is in seconds. What is the tension in the string?

(1) \( \nu = \sqrt{\frac{T}{m/\ell}} \implies T = \frac{\nu^2 \cdot m}{\ell} \)

(2) \( y = 0.005 \sin (21.0x - 419t) \)

where \( A = 0.005 \text{ m} \)

\( k = 21.0 \)

\( \omega = 419 \text{ rad/s} \)

Since \( k = \frac{2\pi}{\lambda} \), \( \lambda = \frac{2\pi}{k} = \frac{2\pi}{21.0} = 0.295 \text{ m} \)

\( \nu = \frac{\lambda}{T} = \lambda f = \frac{2\pi}{k} \cdot \frac{\omega}{2\pi} = \frac{\omega}{k} \)

\( \implies T = \frac{\nu^2 \cdot m}{\ell} = \frac{\omega^2 \cdot m}{k^2 \cdot \ell} = \frac{(419 \text{ rad/s})^2}{(21.0 \text{ m}^{-1})^2} \cdot \frac{0.200 \text{ kg}}{\text{m}} = \)

\( = 79.6 \text{ N} \)

\( \left( \frac{\text{N}}{\text{m}^2 \cdot \text{kg}} \right) = (\text{N}) \)
4. A guitar string has a linear density of $8.30 \times 10^{-4} \text{ kg/m}$. The length of the string is 0.660 m. The tension in the string is 52.0 N.
(a) What is the fundamental frequency of the tone produced when the string is struck?
(b) What are the frequencies of the next two harmonics?
(c) When the fundamental frequency of the string is sounded with a tuning fork of frequency 196.0 Hz, what beat frequency is heard?

\[ f_1 = \frac{\sqrt{\frac{T}{\mu L}}}{2L} = \frac{\sqrt{\frac{52.0 \text{ N}}{(8.30 \times 10^{-4}) \text{ kg/m}}}}{2 \cdot (0.660 \text{ m})} = \frac{250.3 \text{ m/s}}{1.32 \text{ m}} = 189.6 \text{ Hz} = 190 \text{ Hz} \]

\[ v = \sqrt{\frac{T}{\mu L}} \]

\[ f_2 = 2f_1 = 380 \text{ Hz} \]

\[ f_3 = 3f_1 = 570 \text{ Hz} \]

\[ f_{\text{beat}} = |f_1 - f_2| = |189.6 - 196.0| = 6.4 \text{ Hz} \]
5. According to US government regulations, the maximum sound intensity level in the workplace is 90.0 dB. Within one factory, 32 identical machines produce a sound intensity level of 92.0 dB. How many machines must be removed to bring the factory into compliance with the regulation?

\[ B_{32} = 10 \log \frac{32I}{I_0} = 92.0 \text{ dB} \]

\[ B_x = 10 \log \frac{xI}{I_0} = 90.0 \text{ dB} \]

\[ B_{32} - B_x = 2.0 \text{ dB} = 10 \left( \log \frac{32I}{I_0} - \log \frac{xI}{I_0} \right) = \]

\[ = 10 \log \left( \frac{\frac{32I}{I_0}}{\frac{xI}{I_0}} \right) = 10 \log \frac{32}{x} = \]

\[ = 10 \log 32 - 10 \log x \]

\[ 10 \log x = 10 \log 32 - 2 \]

\[ \log x = \log 32 - 0.2 \]

\[ x = 10^{\log 32 - 0.2} = 20 \]

Amount of machines to be removed is

\[ 32 - 20 = 12 \]
A loudspeaker at the base of the cliff emits a pure tone of frequency 3000 Hz. A man jumps from rest from the top of the cliff and safely falls into the net below. How far the man fallen at the instant he hears the frequency of the tone as 3218 Hz the speed of sound is 343 m/s.

1. Stationary emitter - approaching receiver

\[ f' = f \left(1 + \frac{v}{c}\right) \]

\[ f - f = \frac{f v}{c} \]

\[ c = \frac{(f' - f)}{f} \]

\[ v = \frac{c(3218 - 3000)}{343} = 24.92 \text{ m/s} \]

2. 

<table>
<thead>
<tr>
<th>y</th>
<th>v_0</th>
<th>v_1</th>
<th>a</th>
<th>b</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>-24.92 m/s</td>
<td>-9.8 \text{ m/s}^2</td>
<td>?</td>
<td></td>
</tr>
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\[ v_1^2 = v_0^2 + 2ay \]

\[ y = \frac{v_1^2}{2a} = \frac{(24.92 \text{ m/s})^2}{2(-9.8 \text{ m/s}^2)} = -31.7 \text{ m} \]

Distance travelled \( y \) = \( |y| = 31.7 \text{ m} \)