Physics 121A
Autumn 2024

121A - K.TOLICH

Midterm 2
November 14th, 2024

Please use the boxes below to clearly print your name and UW NetID.
Please write within the boxes.

Printed Name	

first *last*

UW Net ID	

(part before @uw.edu)

I certify that the work I shall submit is my own creation, not copied from any source.

Signature ________________________________ **Seat Number** _________________

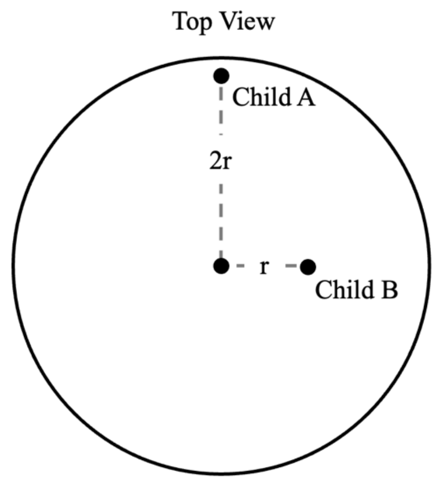
Clearly fill out this cover page and the top portion of the provided bubble sheet with the necessary information.

Do not open the exam until told to do so.
For multi-select questions, you earn partial credit for each correct answer that you choose, but you receive no credit if you choose any incorrect answers.

When prompted, clearly print the information required at the top of each page of this exam booklet.
You can remove the equation sheet(s). Otherwise, keep the exam booklet intact.
You will have 60 minutes to complete the examination.

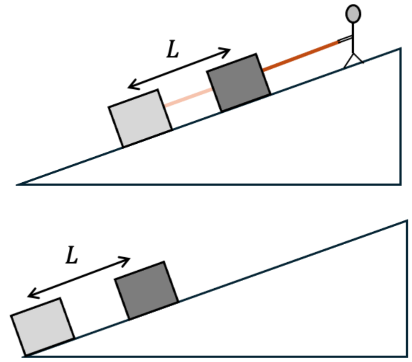
I. [45 points total] Lecture multiple-choice questions

1. [5 points] Two children are on a rotating platform in a playground as shown in the top-view diagram. Child A has mass m and is a distance $2r$ from the center. Child B has mass $2m$ and is a distance r from the center. The platform rotates at a constant angular speed, and the children do not slide on it. How does the frictional force on child A compare to the frictional force on child B?
   A. $f_A > f_B$
   B. $f_A < f_B$
   C. $f_A = f_B \neq 0$
   D. $f_A = f_B = 0$



2. [5 points] The cable of a crane is lifting a 850 kg girder. The girder's speed increases from 0.25 m/s to 2.00 m/s in a distance of 2.90 m. How much work is done by the cable on the girder?
   A. 1.67×10^2 J
   B. 4.14×10^3 J
   C. 2.24×10^4 J
   D. 2.42×10^4 J
   E. 2.58×10^4 J

3. [5 points] A person holds a rope that is attached to a box that is on a slope. They lower the block at constant speed for a distance of L meters. Then the rope breaks, and the box slides another L meters before it reaches the bottom of the slope. The surface of the slope cannot be considered frictionless. How does the thermal energy generated in the first L meters compare to the thermal energy generated in the second L meters?

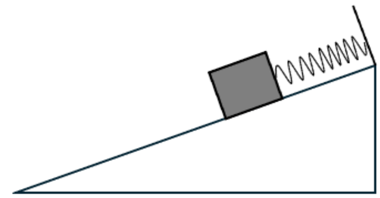


   A. $\Delta E_{\text{th first}} > \Delta E_{\text{th second}}$
   B. $\Delta E_{\text{th first}} < \Delta E_{\text{th second}}$
   C. $\Delta E_{\text{th first}} = \Delta E_{\text{th second}}$
   D. There is not enough information

4. [5 points] Suppose you are lifting a box of mass 0.60 kg straight up at a constant speed with a constant power output of 3.6 W. How long does it take to raise the box a distance 0.80 m?
   A. 0.77 s
   B. 7.5 s
   C. 4.7 s
   D. 1.3 s
   E. Not enough information is given

Use the following scenario for the next two questions.

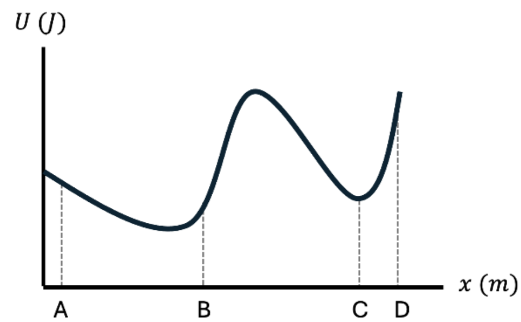
A box of mass 5.0 kg is at rest on an incline that makes an angle of 32° to horizontal. The coefficient of static friction between the box and the incline is 0.44. An ideal spring with a spring constant of 200 N/m is attached to the box. The spring is stretched by 0.10 m.



5. [5 points] What is the frictional force exerted by the incline on the box?
   - A. 18.3 N directed up the incline
   - B. 18.3 N directed down the incline
   - C. 6.0 N directed up the incline
   - D. 6.0 N directed down the incline
   - E. Not enough information is given.

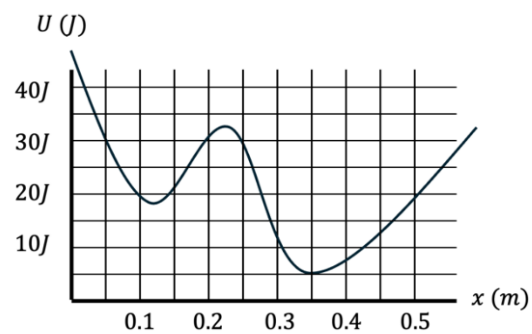
6. [5 points] What is the potential energy stored in the spring?
   - A. 1.0 J
   - B. 2.6 J
   - C. 20 J
   - D. 4.9 J
   - E. None of the above

7. [5 points] A potential energy diagram for a particle subject to a single varying conservative force F acting on it along the x-axis is shown. For full credit, choose all correct statements below. If you choose any incorrect statements, you will get no credit.



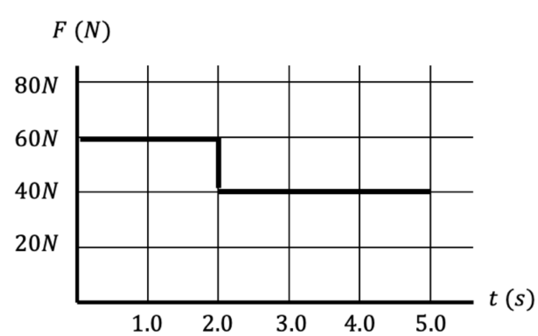
   A. The particle would experience a force of greater magnitude at point A than at point B.
   B. Point C is a stable equilibrium.
   C. At point D, the force exerted on the particle is in the positive direction.
   D. If released from rest at point A, the particle would never reach point C.

8. [5 points] The graph at right shows the potential-energy diagram for a particle as it moves along the x-axis. There is a turning point at $x = 0.5$ m. What is the kinetic energy of the particle at $x = 0.35$ m?



   A. 20 J
   B. 5 J
   C. 15 J
   D. Not enough information is given.

9. [5 points] At $t = 0$ s, a crate is moving with a velocity of -3.2 m/s along the x-axis. Then a time-varying force is applied to the crate, as shown in the graph. At $t = 2.0$ s the speed of the crate is zero. What is its velocity at $t = 5.0$ s?



   A. 6.4 m/s
   B. -6.4 m/s
   C. 3.2 m/s
   D. -3.2 m/s
   E. Not enough information is given.

II. [15 points total] Lab multiple-choice questions
Answer the following three questions based on the methods developed in the labs.

10. [5 points] A police department wants to measure the average speed of cars on a straight road. Two police officers, 1.00 km ± 0.01 km apart, each record the time when a car passes them. They conduct several trials with a test car that tries to move at the same constant speed each time. They find the average time and standard deviation is 0.010 hr ± 0.001 hr. For full credit, choose all correct statements for this experiment below. If you choose any incorrect statements, you will get no credit.

    A. Time is the independent variable, and position is the dependent variable.
    B. Position is the independent variable, and time is the dependent variable.
    C. The fractional uncertainty in the position is larger than the fractional uncertainty in the time.
    D. The fractional uncertainty in the time is larger than the fractional uncertainty in the position.

11. [5 points] Another department repeats the experiment using a different road and a different car moving at a different speed. They find the following values:

    Δx = 3.00 km with a fractional uncertainty of 0.02

    Δt = 0.031 hr with a fractional uncertainty of 0.09

    They want to find the speed of their car $v = \Delta x/\Delta t$. Which of the following is how they could report their best estimate of the speed using the rules developed in lab?

    A. 96.77 ± 8.71 km/hr
    B. 97 ± 9 km/hr
    C. 96.8 ± 1.9 km/hr
    D. 97 ± 2 km/hr
    E. 97 ± 11 km/hr

12. [5 points] A group of students places a toy car on a horizontal surface and measures the time it takes for the car to go from the starting point to the 30 cm mark. They repeat this experiment 100 times. They obtain values that lie between 2.0 s and 3.2 s.

    They calculate the average value of the time and then calculate:

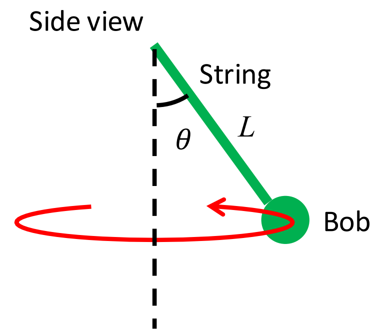
    - the maximum deviation of the time measurements from the average
    - the standard deviation of the time measurements.

    Which of the following would you expect?

    A. The standard deviation would mostly likely be larger than the maximum deviation.
    B. The standard deviation would most likely be smaller than the maximum deviation.
    C. The standard deviation would most likely be equal to the maximum deviation.
    D. Any of the above is equally likely.

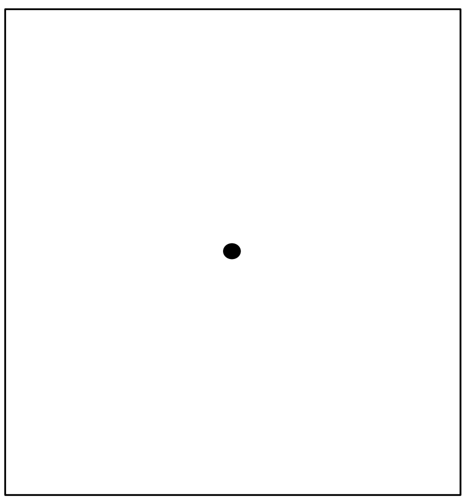
III. [25 points total] Lecture free response questions
<u>You must show your work to get the full credit.</u>

Consider the following scenario for the next two questions.
Consider a conical pendulum of length L. The bob of the pendulum moves in a horizontal uniform circular motion with angular velocity ω. The string of the pendulum makes an angle of θ from vertical as shown.



13. [3 points] In the box below, draw a free-body diagram for the forces acting on the pendulum bob at the moment shown. Make sure to label each force indicating the type of the force, the agent, and the object on which the force acts.

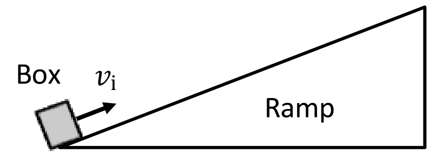
FBD of the pendulumbob



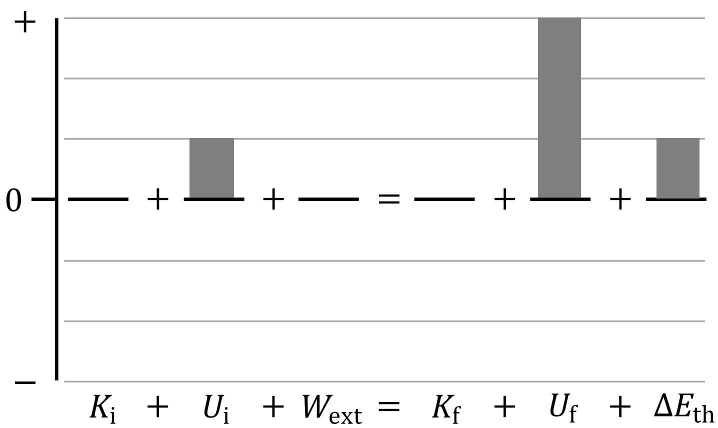
14. [9 points] What is the expression for the length of the string L in terms of θ, ω, and g, the free-fall acceleration?

Use the following scenario for the next two questions.

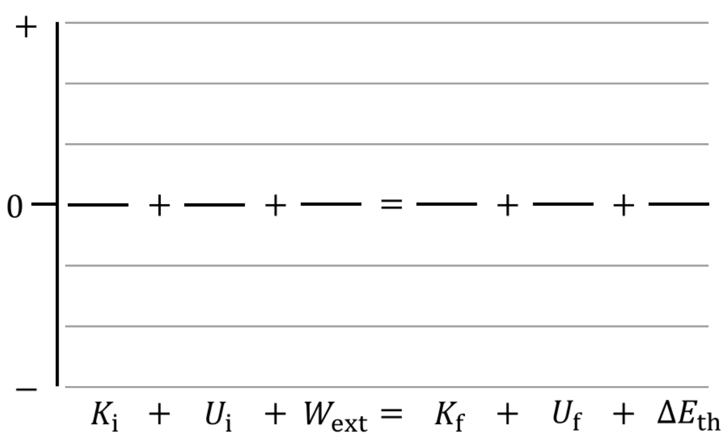
A small box at the bottom of a ramp with a rough surface is moving at an initial velocity of v_i. It then slides up the ramp surface. It finally reaches the maximum height that is below the top of the ramp.



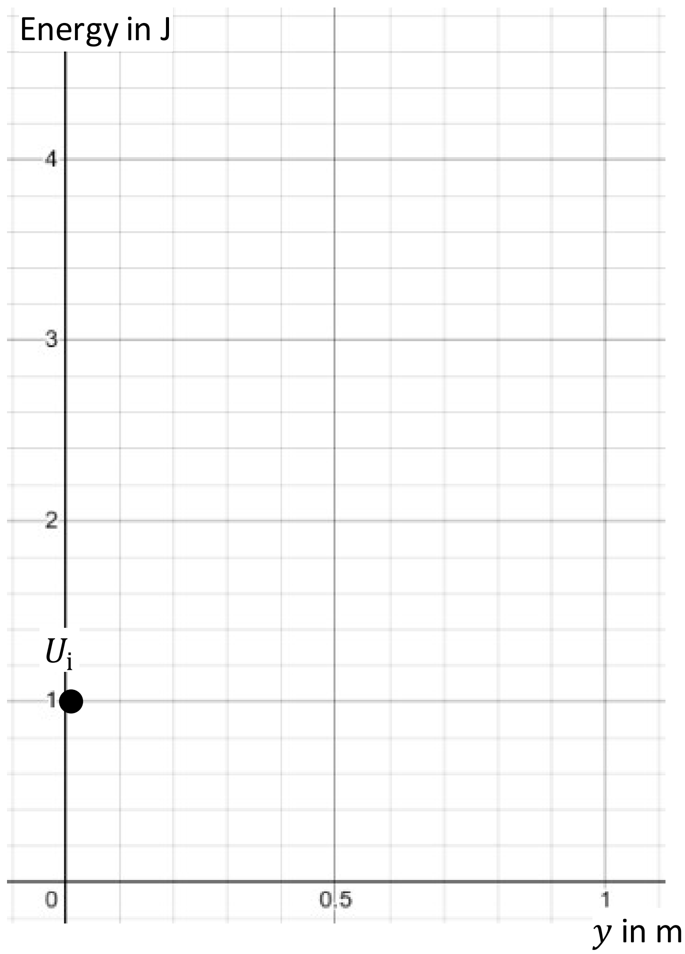
15. [3 points] Consider a system containing the box, the ramp, and the earth. The figure below is an incomplete energy bar chart for the system in this process, from the time the block begins up the ramp with a velocity v_i until it reaches the maximum height. Complete the chart. Make sure to draw it to the correct relative scale. If the quantity is zero, indicate so explicitly.



16. [5 points] Consider another system containing just the box and the ramp. Complete the chart for the same time interval. Make sure to draw it to the correct relative scale compared to the chart in Q15. If the quantity is zero or irrelevant, indicate so explicitly.



17. [5 points] A ball is thrown upward from initial position $y = 0\ \mathrm{m}$. Consider a system that consists of the ball and the earth. As the ball reaches the maximum height of $y = 1\ \mathrm{m}$, the system gains 3 J of gravitational potential energy.
Draw the following curves in the space below and make sure to label them.
   A. Gravitational potential energy versus y-position, $U(y)$. Note that initial gravitational potential energy is already indicated on the graph.
   B. Kinetic energy versus y-position, $K(y)$
   C. Total energy versus y-position, $E_{\mathrm{tot}}(y)$

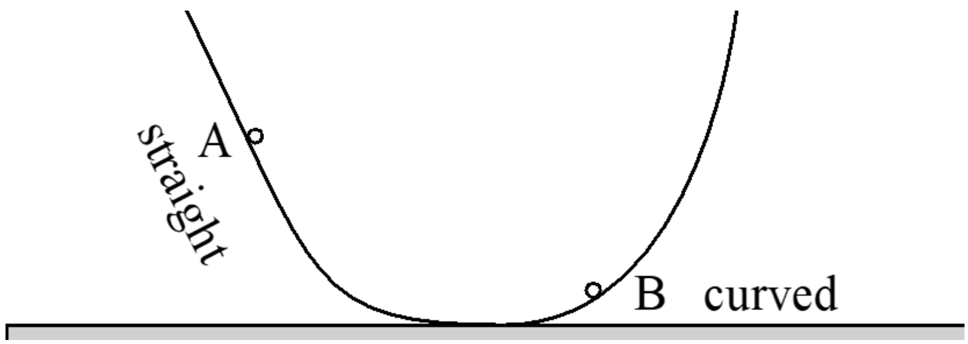


Ignore air resistance.

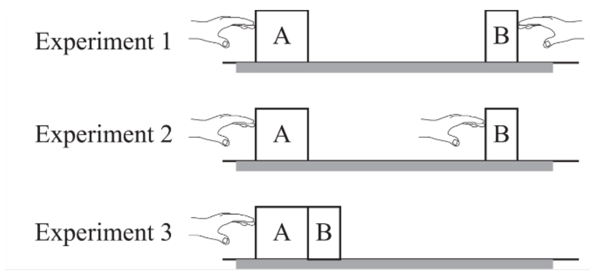
IV. [15 points total] Tutorial free response questions

18. [5 points] A particle slides from point *A* to point *B* along a curved, frictionless ramp as shown in the side-view diagram below. The object never leaves the ramp. At point *A*, the ramp is straight, and the object is speeding up. At point *B* the ramp is curved, and the object is slowing down.

    Draw **four** vectors on the diagram, **two at each point**: one showing the direction of the velocity (labeled *v*) and the other showing the direction of the acceleration (labeled *a*). *If a vector is tangent to the track or is perpendicular to the track, state so explicitly.*



19. [6 points] Three experiments with two blocks are shown at right. Block A has mass $2m_o$, and Block B has mass m_o. **Each hand pushes with a force of magnitude F_o through a displacement of magnitude d_o.**



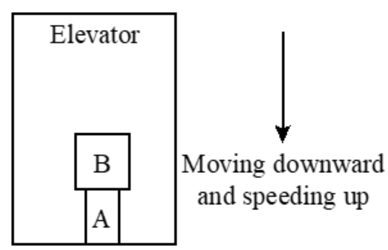
Experiment 1: The blocks are pushed in opposite directions.
Experiment 2: The blocks are pushed in the same direction.
Experiment 3: The blocks are together and pushed to the right.

Consider the system consisting of both blocks in each Experiment.
The surfaces are frictionless.

Rank the total work done on the system in each experiment, $W_{\text{Total},1}$, $W_{\text{Total},2}$, and $W_{\text{Total},3}$, from largest to smallest. If any work is zero, state so explicitly. Explain your reasoning.

20. [4 points] Block A is on the floor of an elevator with Block B on top of it, as shown. The elevator moves downward at increasing speed. Block B has twice the mass of Block A.

Is the net force on block A *greater than, less than,* or *equal to* the net force on block B? Explain.



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Constants

Free-fall acceleration $g = 9.80\ \mathrm{m/s^2}$

Gravitational constant $G = 6.67 \times 10^{-11}\,\mathrm{N\,m^2/kg^2}$

Mathematics

Vector components $\vec{A} = \vec{A}_x + \vec{A}_y = A_x\hat{\imath} + A_y\hat{\jmath}$

Vector magnitude $A = \sqrt{A_x^2 + A_y^2}$

θ ccw from x-axis
$A_x = A\cos\theta$
$A_y = A\sin\theta$
$\theta = \tan^{-1}(A_y/A_x)$

Adding vectors $\vec{C} = \vec{A} + \vec{B}$
$C_x = A_x + B_x$
$C_y = A_y + B_y$

Dot product
$\vec{A}\cdot\vec{B} = AB\cos\alpha$
$\vec{A}\cdot\vec{B} = A_xB_x + A_yB_y$

Cross product
$|\vec{A}\times\vec{B}| = AB\sin\alpha$
$\vec{A}\times\vec{B} = -\vec{B}\times\vec{A}$

Linear motion

Average velocity $\vec{v}_{\mathrm{ave}} \equiv \frac{\Delta\vec{r}}{\Delta t} = \frac{\vec{r}_{\mathrm{f}}-\vec{r}_{\mathrm{i}}}{t_{\mathrm{f}}-t_{\mathrm{i}}}$

Instantaneous velocity $\vec{v} = \frac{d\vec{r}}{dt}$

Instantaneous acceleration $\vec{a} = \frac{d\vec{v}}{dt}$

Constant acceleration (in "s" direction)
$v_{\mathrm{f}s} = v_{\mathrm{i}s} + a_s\Delta t$
$s_{\mathrm{f}} = s_{\mathrm{i}} + v_{\mathrm{i}s}\Delta t + \frac{1}{2}a_s(\Delta t)^2$
$v_{\mathrm{f}s}^2 = v_{\mathrm{i}s}^2 + 2a_s\Delta s$

Motion on inclined plane $a_s = \pm g\sin\theta$

Relative motion $\vec{v}_{\mathrm{CB}} = \vec{v}_{\mathrm{CA}} + \vec{v}_{\mathrm{AB}}$

Circular motion

Angular position $\theta = \frac{s}{r}$

Angular velocity $\omega = \frac{d\theta}{dt}$

Angular acceleration $\alpha = \frac{d\omega}{dt}$

Tangential velocity $v_t = \omega r$

Centripetal acceleration $a_r = \frac{v_t^2}{r} = \omega^2 r$

Tangential acceleration $a_t = \alpha r$

Period $T = \frac{2\pi r}{v} = \frac{2\pi}{\omega}$

Const. angular acceleration
$\omega_{\mathrm{f}} = \omega_{\mathrm{i}} + \alpha\Delta t$
$\theta_{\mathrm{f}} = \theta_{\mathrm{i}} + \omega_{\mathrm{i}}\Delta t + \frac{1}{2}\alpha(\Delta t)^2$
$\omega_{\mathrm{f}}^2 = \omega_{\mathrm{i}}^2 + 2\alpha\Delta\theta$

Force and motion

Newton's 2nd law $\vec{a} = \frac{\vec{F}_{\mathrm{net}}}{m}$

Gravity
$F_{\mathrm{G}} = mg$
$F_{\mathrm{G}} = \frac{GMm}{R^2}$

Maximum static friction $f_{\mathrm{s\,max}} = \mu_{\mathrm{s}}n$

Kinetic friction $f_{\mathrm{k}} = \mu_{\mathrm{k}}n$

Reynolds number $Re = \frac{\rho v L}{\eta}$

Drag (high Re) $F_{\mathrm{drag}} = \frac{1}{2}C_{\mathrm{d}}\rho A v^2$

Drag (low Re) $F_{\mathrm{drag}} = 6\pi\eta r v$

Newton's 3rd law $\vec{F}_{\mathrm{A\,on\,B}} = -\vec{F}_{\mathrm{B\,on\,A}}$

Circular motion
$(F_{\mathrm{net}})_r = \frac{mv_t^2}{r} = m\omega^2 r$
$(F_{\mathrm{net}})_t = ma_t$

Work and energy

Kinetic energy $K = \frac{1}{2}mv^2$

Work by a constant force $W = \vec{F}\cdot\Delta\vec{r}$

Hooke's law $(F_{\mathrm{Sp}})_s = -k\Delta s$

Work done by a spring $W = -\frac{1}{2}k[(\Delta s_{\mathrm{f}})^2 - (\Delta s_{\mathrm{i}})^2]$

Dissipative force $\Delta E_{\mathrm{th}} = f_{\mathrm{k}}\Delta s$

Potential energy $\Delta U = -W_{\mathrm{int}}$

Grav. potential energy $U_{\mathrm{G}} = mgy$

Elastic potential energy $U_{\mathrm{Sp}} = \frac{1}{2}k(\Delta s)^2$

Mechanical energy $\Delta E_{\mathrm{mech}} = \Delta K + \Delta U$

System energy
$\Delta E_{\mathrm{sys}} = \Delta E_{\mathrm{mech}} + \Delta E_{\mathrm{th}}$
$\Delta E_{\mathrm{sys}} = W_{\mathrm{ext}}$

Power $P = \frac{dE_{sys}}{dt}$

$P = \vec{F} \cdot \vec{v}$

Force and potential energy $F_s = -\frac{dU}{ds}$

Impulse and linear momentum

Momentum $\vec{p} = m\vec{v}$

Impulse $\vec{J} \equiv \int_{t_i}^{t_f} \vec{F}(t)dt$

Momentum principle $\Delta\vec{p} = \vec{J}$

Isolated system $\vec{P}_f = \vec{P}_i$

Force $\vec{F} = \frac{d\vec{p}}{dt}$

Elastic collision with $(v_{ix})_2 = 0$

$$(v_{fx})_1 = \frac{m_1 - m_2}{m_1 + m_2}(v_{ix})_1$$

$$(v_{fx})_2 = \frac{2m_1}{m_1 + m_2}(v_{ix})_1$$

Rotation

Center of mass $x_{cm} = \frac{1}{M}\sum_i m_i x_i$

Moment of inertia $I = \sum_i m_i r_i^2$

- Rod (center) $\frac{1}{12}ML^2$
- Rod (end) $\frac{1}{3}ML^2$
- Disk $\frac{1}{2}MR^2$
- Hoop MR^2
- Solid sphere $\frac{2}{5}MR^2$
- Hollow sphere $\frac{2}{3}MR^2$

Parallel-axis theorem $I = I_{cm} + Md^2$

Rotational kinetic energy $K_{rot} = \frac{1}{2}I\omega^2$

Torque $\tau \equiv rF\sin\phi = rF_\perp = Fd$

$\vec{\tau} \equiv \vec{r} \times \vec{F}$

Gravitational torque $\tau_{grav} = -Mgx_{cm}$

Newton's second law for rotation

$$\alpha = \frac{\tau_{net}}{I}$$

Rolling $v_{cm} = R\omega$

$K_{rolling} = \frac{1}{2}I_{cm}\omega^2 + \frac{1}{2}Mv_{cm}^2$

Angular momentum $\vec{L} \equiv \vec{r} \times \vec{p}$

Angular momentum of a particle

$$L_z = mrv_t = mr^2\omega$$

Angular momentum of a rigid body

$$\frac{d\vec{L}}{dt} = \vec{\tau}_{net}$$

$$\vec{L} = I\vec{\omega}$$

Theory of gravity

Law of gravity $F_{1\text{ on }2} = F_{2\text{ on }1} = \frac{Gm_1m_2}{r^2}$

Free-fall acceleration $g = \frac{GM}{r^2}$

Potential energy $U_G = -\frac{Gm_1m_2}{r}$

Satellite speed $v = \sqrt{\frac{GM}{r}}$

Kepler's third law $T^2 = \left(\frac{4\pi^2}{GM}\right)r^3$

Escape speed $v_{escape} = \sqrt{\frac{2GM}{R}}$

Geosynchronous orbit $r_{geo} = \left(\frac{GM}{4\pi^2}T^2\right)^{1/3}$