Last Name: _______________ First Name: _____________________ NetID: _________________

Discussion Section: ______ Discussion TA: ____

Instructions – ***Turn off your cell phone and put it away. Please keep your calculator on your own desk. Calculators may not be shared.***

This is a closed book exam. You have (1.5) hours to complete it.

I. *Fill in ALL the information requested on the lines above and sign the Formula Sheet.*

II. At the end of this exam, you must return this Exam Booklet complete with all pages, including the formula sheet, along with your answer sheet.

III. If you do not turn in a complete Exam Booklet, including the formula sheet, your Answer Sheet will not be graded and you will receive the grade AB (Absent) for this exam. Kindly paper clip the Answer Sheet to the Exam Booklet.

1. Fill in the circle for each intended input (until there is no white space visible) – 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. 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 near the middle of your answer sheet. **DO THIS NOW!**

5. Stop **now** and double-check that you have bubbled in all the information requested in 2 through 4 above and that your marks meet the criteria in 1 above. Check that you do not have more than one circle marked in any of the columns.

6. 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.

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

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

CHECK NOW THAT YOU HAVE COMPLETED ALL OF THE ABOVE STEPS

*Before starting work, check to make sure that your Multiple Choice test booklet is complete. You should have **19** questions and a Formula Sheet at the end. Grading policy is explained on page 2.*

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 near the middle of your answer sheet. **DO THIS NOW!**

Exam Grading Policy—

The exam 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 four answers, one of which is the correct answer, you earn **1.5** points.
(d) If you mark five answers, one of which is the correct answer, you earn **1.2** points

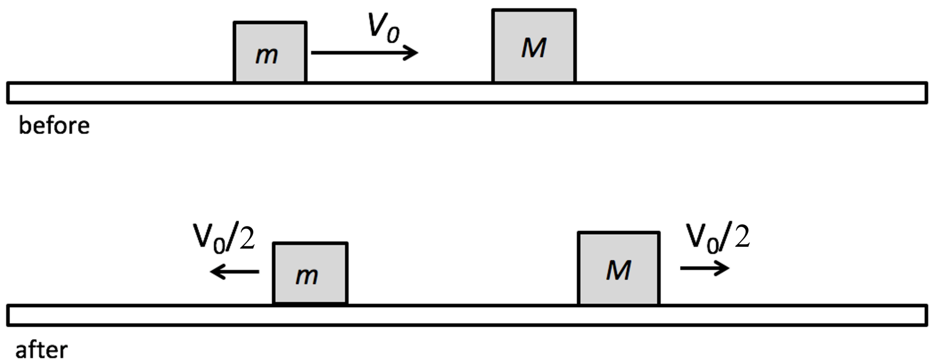
MC3: *multiple-choice-three-answer questions, each worth 3 points.* **Partial credit will be granted as follows.**

(a) If you mark only one answer and it is the correct answer, you earn **3** points.
(b) If you mark two answers, one of which is the correct answer, you earn **1.5** points.
(c) If you mark three answers, one of which is the correct answer, you earn **1** point.

MC2: *multiple-choice-three-answer questions, each worth 2 points.* **Partial credit will be granted as follows.**

(a) If you mark only one answer and it is the correct answer, you earn **2** points.
(b) If you mark two answers, one of which is the correct answer, you earn **1** point.

The next two questions pertain to the situation described below.



A box of mass m slides on a straight frictionless horizontal track with an initial speed V_0. It collides and bounces off a box of mass M which is initially at rest. After the collision the box having mass m is moving to the left with speed, $V_0/2$ and the box having mass M is moving to the right with the same speed, $V_0/2$.

1) How are the masses of the two boxes, M and m, related?

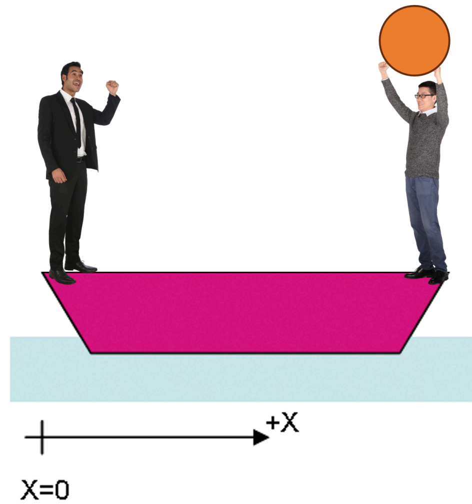
a. $M = 3m/2$
b. $M = 4m$
c. $M = 2m$
d. $M = 2m/3$
e. $M = 3m$

2) Which of the following statements is true?

a. The collision is not elastic.
b. The collision is elastic.
c. We need to know the masses of the boxes in order to determine whether or not the collision is elastic.

The next three questions pertain to the situation described below.

Two people each with mass 50 kg are at either end of a 24 kg boat which is L = 6 m long as shown in the figure. The person on the right side of the boat is holding a sphere of mass 12 kg. The water is still and the left edge of the boat is at x = 0 m



3) What is the x coordinate of the center of mass of the boat, sphere and two people system?

a. 5.16 m
b. 3 m
c. 3.26 m

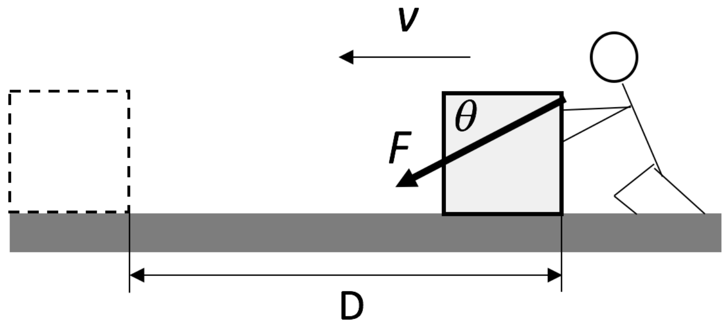
4) The person on the right throws the ball toward the person on the left with a speed $|V_{ball}|$ = 9 m/s. What is the speed of the boat while the ball is in the air?

a. 0.871 m/s
b. 4.5 m/s
c. 0.794 m/s

5) The person on the left catches the ball. What is the new location of the left edge of the boat?

a. 0.265 m
b. 0.837 m
c. -0.265 m
d. 0.529 m
e. 0.581 m

The next three questions pertain to the situation described below.



A student is pushing a box of mass $M = 20\ kg$ across a level floor at a constant speed of $v = 1.5\ m/s$. The student pushes on the box with a downward force $F = 160\ N$ at an angle $\theta = 31°$ below the horizontal. The box moves a distance $D = 14\ m$ across the floor. The coefficient of kinetic friction between the box and the floor is μ_k.

6) While the box moves a distance D across the floor, which of the following quantities are non-zero?

a. Work done by the box on the person
b. Work done by normal force on the box
c. Total work done on the box

7) What is the work done on the box by friction as it moves a distance D across the floor?

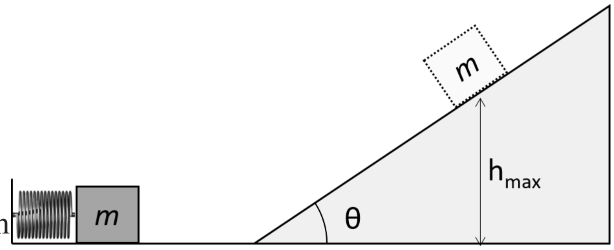
a. W_{fr} = -1154 J
b. W_{fr} = -1920 J
c. W_{fr} = 0 J
d. W_{fr} = -2747 J
e. W_{fr} = -2240 J

8) After the student pushed the box for a distance D as described above, the floor material changes such that μ_k reduces by half. What would be the speed of the box after traveling another D in the new surface?

a. v_{final} = 2.1 m/s
b. v_{final} = 6.9 m/s
c. v_{final} = 21.4 m/s
d. v_{final} = 9.9 m/s
e. v_{final} = 0 m/s

The next three questions pertain to the situation described below.

A block of mass $m = 0.45$ kg sits against a compressed spring of stiffness $k = 175$ N/m placed next to a frictionless inclined plane making an angle $\theta = 27°$ from the horizontal, as shown. The spring is released such that the mass acquires speed $v = 3.2$ m/s as it loses contact with the spring.



9) What is the maximum height h_{max} that the mass reaches?

a. $h_{max} = 0.75$ m
b. $h_{max} = 0.58$ m
c. $h_{max} = 0.81$ m
d. $h_{max} = 0.52$ m
e. $h_{max} = 0.69$ m

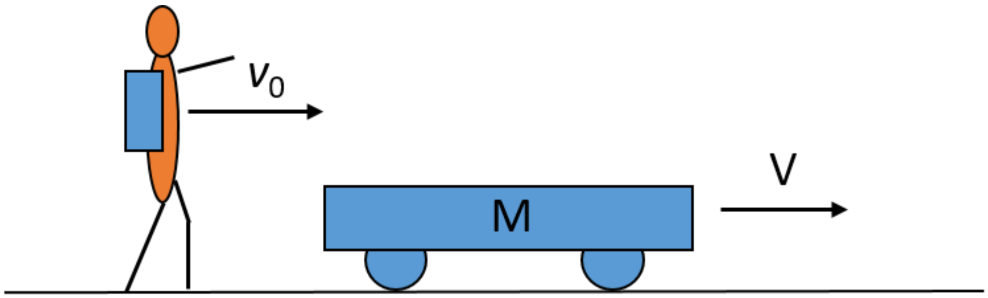
10) By how much must the spring have been compressed relative to its relaxed length?

a. $x = 0.229$ m
b. $x = 0.325$ m
c. $x = 0.162$ m

11) Now suppose that we add friction to the surface of the inclined plane, using material with coefficient of kinetic friction $\mu = 0.45$. What is the new maximum height h_{max} that the mass reaches?

a. $h_{max} = 0.373$ m
b. $h_{max} = 0.871$ m
c. $h_{max} = 0.163$ m
d. $h_{max} = 0.277$ m
e. $h_{max} = 0.949$ m

The next three questions pertain to the situation described below.



A four-wheel cart of mass $M = 85$ kg is moving along a horizontal surface with a constant velocity $V = 4.5$ m/s relative to the ground. A person of mass $m_1 = 62$ kg carrying a backpack of $m_2 = 8$ kg runs and catches up to the cart, and then jumps onto the cart. Just before landing on the cart, the person is moving parallel to the ground and the velocity of the center of mass of the system including the person, backpack and cart is $V_{CM} = 6$ m/s.

12) What is the speed of the person just before landing on the cart?

a. $v_0 = 7.8$ m/s
b. $v_0 = 6.4$ m/s
c. $v_0 = 0.54$ m/s
d. $v_0 = 13$ m/s
e. $v_0 = 11$ m/s

13) What is the horizontal momentum of the person after landing on the cart?

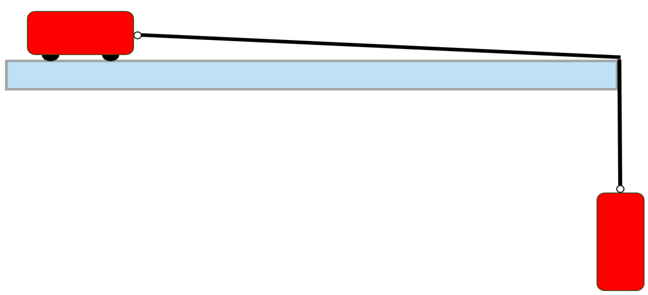
a. $p_f = 279$ kg m/s
b. $p_f = 484$ kg m/s
c. $p_f = 372$ kg m/s

14) The person now holds the backpack off the back of the cart and lets go. The backpack falls to the ground. What happens to the speed of the cart when the backpack is dropped?

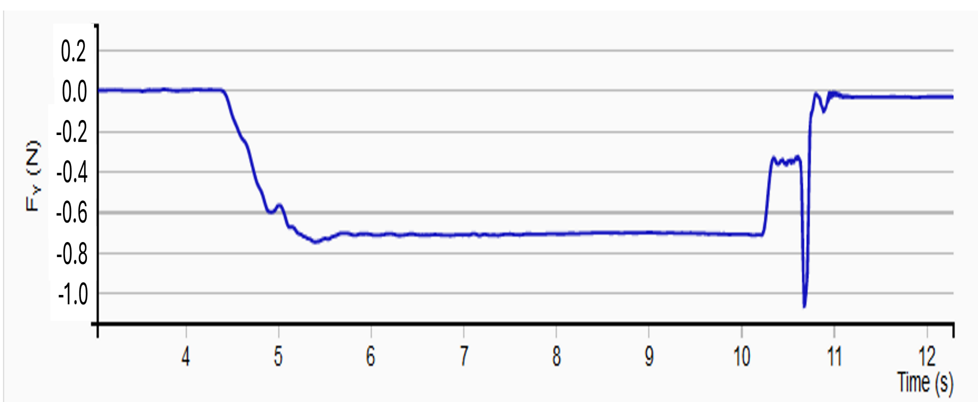
a. decreases
b. increases
c. remains the same

The next three questions pertain to the situation described below.

A group of students, resident on a new station on the surface of the planet Mars, repeats P211 Lab 5. A simplified diagram of the Lab 5 setup is shown below. Two IOLabs, each with mass 0.20 kg, are connected by a string, which attaches to the force sensor on the long end of each device. The first IOLab is placed wheels down on a horizontal table top. With the force sensors running (and recording data), the second IOLab is initially placed on the table top, then let to hang over the edge of the table (as in the figure) while the first one is held in place. Then the first IOLab is released and let to roll across the table top as the second falls. Data acquisition is stopped after the second IOLab hits the floor.



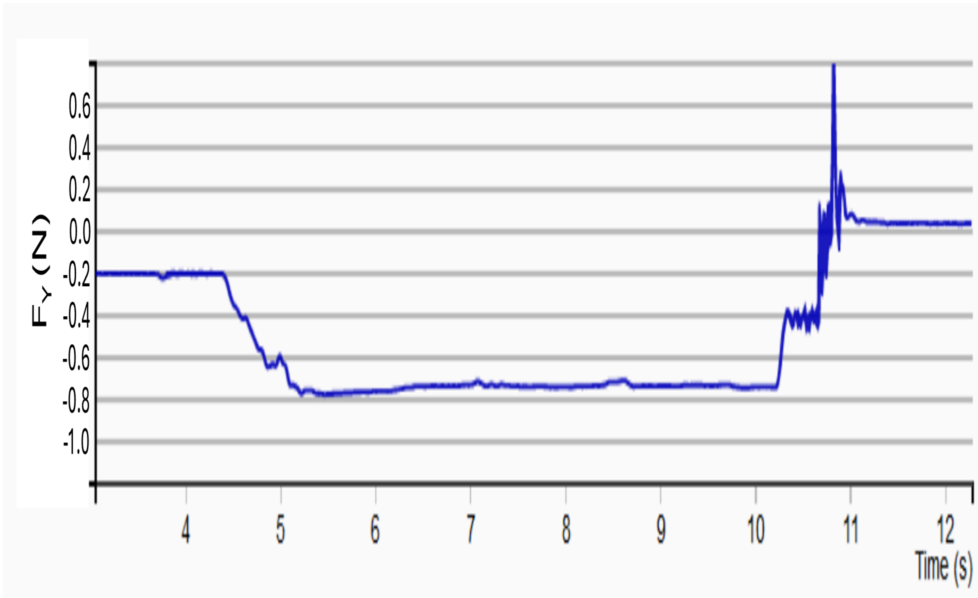
15) The image below shows the force probe data from the second IOLab during the processes described above.



Based on the above data, what is the best value for the gravitational acceleration on the surface of Mars?

a. 1.7 m/s^2
b. 3.5 m/s^2
c. 5.5 m/s^2

16) A second group of students on the station performs the same experiment and records the data shown below. From these data, they obtain a larger value for the gravitational acceleration.

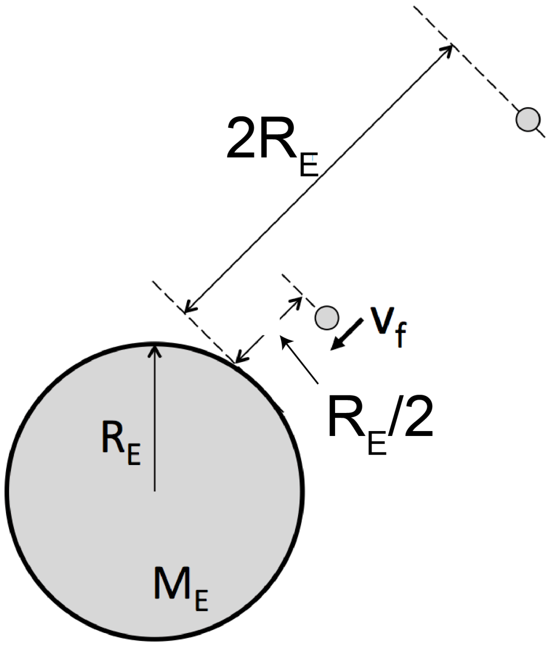


Which value is correct?

a. The first value is correct
b. The second value is correct

17) Is the incorrect value an example of statistical or systematic error?

a. systematic
b. statistical



A rock is released from rest at a distance two times of the earth radius (2 R_e) above the <u>surface</u> of the Earth as shown in the figure. Useful constants for this problem are the universal gravitational constant $G = 6.67 \times 10^{-11}$ Nm^2/kg^2, the mass of the Earth $M_e = 5.97 \times 10^{24}$ kg, and the radius of the Earth $R_e = 6.38 \times 10^6$ m.

18) What is the speed of the rock, v_f, when it has fallen to a distance $R_e/2$ above the surface of the Earth?

a. $v_f = 19352$ m/s
b. $v_f = 6451$ m/s
c. $v_f = 3950$ m/s
d. $v_f = 3225$ m/s
e. $v_f = 11188$ m/s

This is the last multiple choice question of the exam. Make sure you have completed your bubble sheet, then you can work on the free response page of the exam. Be sure to write your name, netid and section on the free response page.

19) Did you check your answer sheet to ensure you

1. Entered your netid
2. Entered your exam version
3. Marked answers for all 19 questions (including this one)

a. Yes (I did all 3)
b. No (I did not enter my netid)
c. No (I did not enter my exam version)

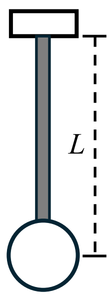
Name: ________________________________ NetID: __________ Disc. Section: _____

Physics 211 – Exam 2 – Free Response Question

- Show your work and thinking clearly. Points will not be given if you just give the final answers without showing your work.
- **For this problem, you are only allowed to use the formulas in the formula sheet. If your solution uses other formulas that you may have memorized, points will be deducted.**

A pendulum consists of a ball of mass $M = 0.8$ kg at the end of a very light rod. The end of the rod is attached to a hinge, such that the rod is free to swing up and down without friction, as shown in the figure. The distance from the end of the rod to the center of the ball is $L = 30$ cm.

(a) The pendulum is initially at rest. You rotate the pendulum by an angle of 90º and release it from rest. What is the speed of the ball when it is at the lowest point of its trajectory? (3 points)



(b) The pendulum is at rest again. A bullet of mass $m = 6$ grams is fired horizontally into the center of the ball. After the collision, the bullet and ball swing back and forth. During that time (i.e., after the collision), which of the following quantities are conserved for the set ball + bullet + rod: horizontal momentum, vertical momentum, and mechanical energy? Explain your reasoning. (3 points)

(c) The velocity of the bullet immediately before hitting the ball is $v = 180$ m/s. What is the speed of the set ball + bullet right after the collision? (3 points)

(more questions on the back page)

(d) What is the maximum height achieved by the set ball + bullet with respect to the initial vertical position of the ball? (4 points)

(e) The experiment in part (b) is repeated under different conditions. The pendulum is at rest and an identical bullet is fired horizontally into the center of the ball, but from a different distance. This time the bullet pierces the ball and exits it horizontally with half of its incoming speed. If the ball's maximum vertical displacement after the collision is $h = 5$ cm, what was the speed of the bullet right before it hit the ball? (7 points)

Kinematics
$\vec{v} = \vec{v}_0 + \vec{a}t$
$\vec{r} = \vec{r}_0 + \vec{v}_0 t + \frac{1}{2}\vec{a}t^2$
$v^2 = v_0^2 + 2a\left(x - x_0\right)$
$g = 9.81\ \mathrm{m/s^2} = 32.2\ \mathrm{ft/s^2}$
$\vec{V}_{\mathrm{A,C}} = \vec{V}_{\mathrm{A,B}} + \vec{V}_{\mathrm{B,C}}$

Uniform Circular Motion
$a = v^2/r$
$v = \omega r$
$\omega = 2\pi/T = 2\pi f$

Dynamics
$\vec{F}_{\mathrm{net}} = m\vec{a} = d\vec{p}/dt$
$\vec{F}_{\mathrm{A,B}} = -\vec{F}_{\mathrm{B,A}}$
$F = mg$ (near Earth's surface)
$F_{12} = Gm_1m_2/r^2$ (in general)
$F_{\mathrm{spring}} = -k\Delta x$

Friction
$f = \mu_{\mathrm{k}}N$ (kinetic)
$f \leq \mu_{\mathrm{s}}N$ (static)

Work & Kinetic Energy
$W = \int \vec{F} \cdot d\vec{l}$
$W = \vec{F} \cdot \vec{\Delta r} = F\,\Delta r \cos\theta$ (constant force)
$W_{\mathrm{grav}} = -mg\Delta y$
$W_{\mathrm{spring}} = -k\left(x_2^2 - x_1^2\right)/2$
$K = mv^2/2$
$W_{\mathrm{net}} = \Delta K$

Potential Energy
$U_{\mathrm{grav}} = mgy$ (near Earth's surface)
$U_{\mathrm{grav}} = -GMm/r$ (in general)
$U_{\mathrm{spring}} = kx^2/2$
$\Delta E = \Delta K + \Delta U = W_{\mathrm{nc}}$

Power
$P = dW/dt$
$P = \vec{F} \cdot \vec{v}$

System of Particles
$\vec{R}_{\mathrm{CM}} = \sum m_i\vec{r}_i / \sum m_i$
$\vec{V}_{\mathrm{CM}} = \sum m_i\vec{v}_i / \sum m_i$
$\vec{A}_{\mathrm{CM}} = \sum m_i\vec{a}_i / \sum m_i$
$\vec{P} = \sum m_i\vec{v}_i$
$\sum \vec{F}_{\mathrm{ext}} = M\vec{A}_{\mathrm{CM}} = d\vec{P}/dt$

Impulse
$\vec{I} = \int \vec{F}\,dt$
$\Delta\vec{P} = \vec{F}_{\mathrm{avg}}\Delta t$

Collisions
If $\sum \vec{F}_{\mathrm{ext}} = 0$ in some direction, then $\vec{P}_{\mathrm{before}} = \vec{P}_{\mathrm{after}}$ in this direction:
$\sum m_i\vec{v}_i$ (before) $= \sum m_i\vec{v}_i$ (after)

In addition, if the collision is elastic:

- $E_{\mathrm{before}} = E_{\mathrm{after}}$
- *Rate of approach = Rate of recession*
- *The speed of an object in the Center-of-Mass reference frame is unchanged by an elastic collision.*

Rotational Kinematics
$s = R\theta$, $v = R\omega$, $a = R\alpha$
$\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$
$\omega = \omega_0 + \alpha t$
$\omega^2 = \omega_0^2 + 2\alpha\Delta\theta$

Rotational Dynamics
$I = \sum m_i r_i^2$
$I_{\mathrm{parallel}} = I_{\mathrm{CM}} + MD^2$
$I_{\mathrm{disk}} = I_{\mathrm{cylinder}} = \frac{1}{2}MR^2$
$I_{\mathrm{hoop}} = MR^2$
$I_{\text{solid-sphere}} = \frac{2}{5}MR^2$
$I_{\text{spherical-shell}} = \frac{2}{3}MR^2$
$I_{\text{rod-cm}} = \frac{1}{12}ML^2$
$I_{\text{rod-end}} = \frac{1}{3}ML^2$
$\tau = I\alpha$ (rotation about a fixed axis)
$\tau = \vec{r} \times \vec{F},\ |\tau| = rF\sin\phi$

Work & Energy
$K_{\mathrm{rotation}} = \frac{1}{2}I\omega^2$
$K_{\mathrm{translation}} = \frac{1}{2}MV_{\mathrm{CM}}^2$
$K_{\mathrm{total}} = K_{\mathrm{rotation}} + K_{\mathrm{translation}}$
$W = \tau\theta$

Statics
$\sum \vec{F} = 0,\ \sum \tau = 0$ (about any axis)

Angular Momentum
$\vec{L} = \vec{r} \times \vec{p}$
$L_z = I\omega_z$
$\vec{L}_{\mathrm{total}} = \vec{L}_{\mathrm{CM}} + \vec{L}^*$
$\tau_{\mathrm{ext}} = d\vec{L}/dt$
$\tau_{\mathrm{cm}} = d\vec{L}^*/dt$
$\Omega_{\mathrm{precession}} = \tau/L$

Simple Harmonic Motion
$d^2x/dt^2 = -\omega^2 x$ (differential equation for SHM)
$x\left(t\right) = A\cos\left(\omega t + \phi\right)$
$v\left(t\right) = -\omega A\sin\left(\omega t + \phi\right)$
$a\left(t\right) = -\omega^2 A\cos\left(\omega t + \phi\right)$
$\omega^2 = k/m$ (mass on spring)
$\omega^2 = g/L$ (simple pendulum)
$\omega^2 = mgR_{\mathrm{CM}}/I$ (physical pendulum)
$\omega^2 = \kappa/I$ (torsion pendulum)

General Harmonic Transverse Waves
$y\left(x,t\right) = A\cos\left(kx - \omega t\right)$
$k = 2\pi/\lambda$, $\omega = 2\pi f = 2\pi/T$
$v = \lambda f = \omega/k$

Waves on a String
$$v^2 = \frac{F}{\mu} = \frac{\text{(tension)}}{\text{(mass per unit length)}}$$
$\overline{P} = \frac{1}{2}\mu v\omega^2 A^2$
$$\frac{d\overline{E}}{dx} = \frac{1}{2}\mu v\omega^2 A^2$$
$$\frac{d^2y}{dx^2} = \frac{1}{v^2}\frac{d^2y}{dt^2}\ \text{(wave equation)}$$

Fluids
$$\rho = \frac{m}{V}$$
$$P = \frac{F}{A}$$
$A_1v_1 = A_2v_2$
$P_1 + \frac{1}{2}\rho v_1^2 + \rho g_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2$
$F_{\mathrm{B}} = \rho_{\mathrm{liquid}} g V_{\mathrm{liquid}}$
$$F_2 = F_1\frac{A_2}{A_1}$$

Uncertainties
$$\delta = \frac{\sigma}{\sqrt{N}}$$
$$t' = \frac{|\mu_{\mathrm{A}} - \mu_{\mathrm{B}}|}{\sqrt{\delta_{\mathrm{A}}^2 + \delta_{\mathrm{B}}^2}}$$