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The Physics of Helm

A Practical Approach to the Knowledge of Nature

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Abstract

In this expository paper, we provide a rudimentary overview on a multitude of physics techniques that are employed where accuracy is a necessity[1]. The course begins by covering elementary kinematics to provide a broad understanding of basic mechanical laws such as 2-dimensional projectile motion. Later covered are basic dynamics and eventually more abstract ideas such as quantum physics.
Keywords: Physics, Helm, Atwood, Dab, *Skip it!*©, Meter Stick of Motivation, Iron Rod of Inspiration, SkyZone©

1 Introduction

Physics. The true science, the pure science.[2] Words truly cannot describe the absolute joy which physics can bring to the physicser, which is why we will use numbers. To physics is to be one with nature, to be one with the derivations, to live, breathe, and shit physics. This is your guide to becoming physics. Helm (2016-2017)

1.1 Significant Figures

As of recent scientific analysis, one member of the scientific community expresses that "Significant figures are obsolete"[3]

0. A perfect physics world is an environment in which the variables of the equation are the only variables which are effecting the system
1. Naturally, this is in the perfection of a perfect physics world[0]
2. Purest science, not purest discipline `https://xkcd.com/435/`
3. Quote (*sic*) Robert Helm, Sept. 2016

Contents

2 Quotes of the Master

- *“Do any of you guys mosh?"*
- *“Any skydivers out there?"*
- *“Equal and ...."*
- *“Meter Stick of Motivation or Iron Rod of Inspiration?"*
- *“Do you want to get together and calculate the gravitational force between us?"*
- *“The mean gang-bangers of Worcester refer to ‘big G’ as ‘Cap G’"*
- *“Newton discovered gravity when he saw the apple fall from the moon"*
- *“Electrons are similar to a drunk guy who just hit a bunch of fraternities"*
- *“Now that we are done, I’ll do the ceremonial dropping of the marker and the dab"*
- *“Getting a satellite into space... I guess it is rocket science... but it’s very simple."*
- *“I’ve been a second semester senior for 24 years"*
- *“Honors Physics is an interesting animal... I mean that figuratively, not literally."*
- *“Teacher Rule No. 103: Once I test you on a concept, you are free to forget. Yet here I am, asking you to recall something all the way from the 1st quarter. It’s not good... it’s not good. I have to stop using words like learn, teach, understand. They don’t belong here..."*
- *“A Russian scientist did an experiment with crashing an airplane into the nuclear silos"*
- *“If you come into school with a 22 caliber, you will get the superlative ‘most likely to have an address in Greatersford PA’"*
- *“We should take a field trip to skyzone"*
- *“Ya know the gangbangers spillin’ some of their 40s when one of their brethren goes down"*
- *“Anyone ever go to SkyZone©?"*
- *“Just dump it in the bin"*
- *“Anyone out there a sports better on the side?"*

- *"The bookies make their money off the juice. Some of your best numbers people make the best bookies."*
- *"Mr. Helm has left the building"*
- *"You guys are going to be the movers and the shakers"*
- *"I'm not blaming you, I'm blaming this system"*
- *"I did pretty good in chemistry, but I didn't kick a-[rings bell]"*
- *"We will drone your [rings bell] into oblivion"*
- *"When you're young your bones are flexible, which is what makes babies bounce"*
- *"thing number two is on a chair, my foot is on the hard wood, thing number two jumps off the chair and lands on my foot"*
- *"We had a week without the kids; they had cages in the basement with bowls of water and bowls of food"*
- *"News headline: 'Science teacher beaten by wife'"*
- *"Some time in your life you will probably rent a U-haul truck, and you will be carrying around all of your sh-[rings bell]–tuff"*
- *"Ya know, around Christmas time bubbles bounce"*
- *"I'm putting together a crew so we can be pirates, like off the coast of Somalia or something"*
- *"You might not know this, but Ben was actually a Montgomery County junior sumo-wrestler"*
- *"I need you guys to think of yourselves as the ambassadors of quam"*
- *"The science fair guys kicked B - U - Double T in science fair"*
- *"The fabric of the universe would fall apart... and that's not good"*
- *"Physics is really just the study of equations"*
- *"Hey, lets invent some carbonated water to spice things up a little"*
- *"I hate to admit it, but you're [Period 5A] probably my smartest physics class"*
- *"There are little green men in there [the keyboard] that yell out "here comes the finger""*
- *"Did you ever see Mr.Physics? The little ball guy? Hes a phenomenal artist you should see him live"*

- *“I have a planet colonization team, the requirements to get in are pretty strict though. You have to be an ex-swedish model to join. (don’t tell my wife)"*
- *“Here, I’ll bring my meterstick of motivation it’ll help you reflect "*
- *“Its not the horse that can go the fastest, its the one that can keep the cart from rolling down the hill"*
- *“Just dump it in the pile"*
- *“Just wait until we get from the nano stage to the pico stage, then there will be like, super super, ya know... stuff"*
- *“And that’s all of physics guys. Every year I drop a pen, and this year I’m adding a dab"*
- *“I’d tell you a story but I’m not gonna"*

Any {} out there?

{} = skydivers, tennis players, baseball players, swimmers, basketball players, skip it fans, combat kiters, dabbers, football players, track runners, people with superpowers, sports betters on the side, 3rd degree parkourers, late night pool hustlers, painters, people who want to make money, Russians, French People

2.1 Testimonials

- ***"I am become physics, the destroyer of tests."*** *- Satvik Kakkar, 1993*
- ***"I couldn't get a good grasp until we added friction to our equations."*** *- William Gulian, 2006*
- ***"We are many test. I don't am cheat."*** *- Karthik Yegnesh, 2001*
- ***"Mr. Bruce Outland is the best chemistry teacher I have ever had."*** *- Dr. Benjamin Rippley PhD, 2017*
- ***"Tengo el poder de physics"*** *- Sahas Kurumety, El master de espanel, 2018*
- ***""*** *- Achyut*

3 Cooking With Helm[4]

3.1 Penn State Dinner

If you find yourself looking for a scrumptious dinner during your stay at the luxurious Penn State University, find yourself a **ZESTY** can of tomato sauce and proceed [to] *dump* in the microwave.

- ***"Tastes just like tomato soup for 25 cents!"*** *- Robert Helm, Award Winning Chef*

4. Helm is of course a shortened alias of Chef Robert Helm, a globally respected culinary artist.

4 Vector Calculations

4.1 Vectors

Vectors are commonly written in two different forms.

Component Form	$\langle x, y \rangle$ or $\langle v_x, v_y \rangle$
Helm Form	V @ $\theta = 30°$

Vectors are quantities that have a magnitude (or length) and a direction. In component form, this information is encoded as a horizontal distance x and vertical distance y. In Helm form, the length is V and the direction is encoded as an angle θ.

By convention, u, v, and w with ($\vec{u}$) or without (u) an arrow are vectors. However, other variables may be a vector in context.

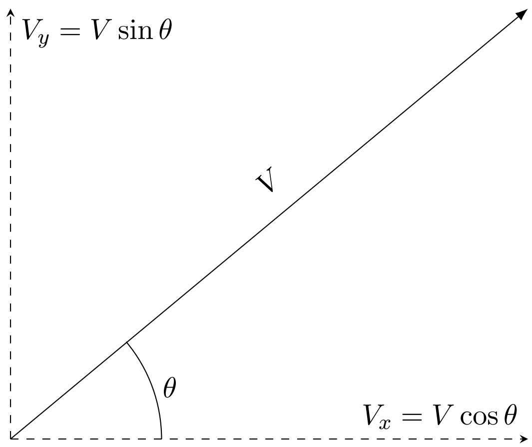


Figure 1: Visualization of V_x and V_y

Component form and Helm form can both represent the same vectors, but to convert between them, equations must be used. Using the standard trigonometry functions, Helm form can be converted to component form with

$$\vec{u}_x = V\cos\theta \text{ and } \vec{u}_y = V\sin\theta$$

where V is the length of the vector in Helm form, and θ is the angle of the vector. To convert from component form to Helm form, an equation based off the Pythogorean theorem can be used to calculate the length of the vector:

$$V = \sqrt{\vec{u}_x{}^2 + \vec{u}_y{}^2}$$

Calculating θ involves using $\tan^{-1}$: (Note that the y component is in the numerator)

$$\theta = \tan^{-1}\left(\frac{\vec{u}_y}{\vec{u}_x}\right)$$

Vectors can be added: $\vec{u}+\vec{v}=\vec{w}$. Graphically, this can be done by drawing each vector tip-to-tail, with the tail of each vector touching the tip of the previous. Numerically, vectors can be added by summing each component in component form (eg. $\langle 1,2\rangle + \langle 4,6\rangle = \langle 5,8\rangle$). A vector written in Helm form must be converted to component form in order to add them.

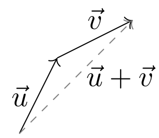


Figure 2: Vector addition

Vector subtraction works identically to vector addition except each component is subtracted:

$$\vec{u}-\vec{v}=\langle u_x - v_x, u_y - v_y\rangle$$

Vectors in Helm form must be converted to component form in order to subtract them.[5]

4.2 Component Vector Equations

$$V_f = \sum V_i = V_1 + V_2 + V_3 + ... \tag{1}$$

$$V_f = \sqrt{\left(\sum V_x\right)^2 + \left(\sum V_y\right)^2} \tag{2}$$

$$\theta_f = \sin^{-1}\left(\frac{\sum V_y}{V_f}\right) \tag{3}$$

$$\theta_f = \cos^{-1}\left(\frac{\sum V_x}{V_f}\right) \tag{4}$$

$$\theta_f = \tan^{-1}\left(\frac{\sum V_y}{\sum V_x}\right) \tag{5}$$

4.3 Single Vector Equations

Where the given vector is of magnitude V at angle θ

$$V_x = V\cos\theta \tag{6}$$

$$V_y = V\sin\theta \tag{7}$$

$$V = \sqrt{V_x^2 + V_y^2} \tag{8}$$

$$\theta = \sin^{-1}\left(\frac{V_y}{V}\right) \tag{9}$$

$$\theta = \cos^{-1}\left(\frac{V_x}{V}\right) \tag{10}$$

$$\theta = \tan^{-1}\left(\frac{V_x}{V_y}\right) \tag{11}$$

5. This is a common theme. Many vector operations must be converted to component form to be computed.

5 Kinetics

An elementary branch of classical mechanics concerning the causes and effects of basic motion. The motion equations describe how objects move.

5.1 Motion Equations

Motion equations describe how an object moves under constant acceleration or constant velocity.

$$a = \frac{v - V_0}{t} \tag{12}$$

$$v = V_0 + a \cdot t \tag{13}$$

$$d = \frac{v + V_0}{2} \cdot t \tag{14}$$

$$d = V_0 \cdot t + \tfrac{1}{2} \cdot a \cdot t^2 \tag{15}$$

$$v^2 - V_0^2 = 2 \cdot a \cdot d \tag{16}$$

5.2 Gravitational Acceleration on a slope

$$a = g \sin\theta \tag{17}$$

See equation 52 to take friction into account

6 Projectile Motion

A study of an object's path of motion when launched relative to a surface with downward gravitational acceleration

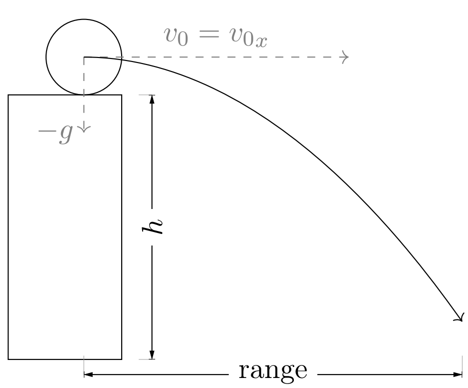
6.1 Branches of Projectile Motion

Elementary projectile motion is broken up into 3 cases

- Case 1: Object launched from a height, with $\theta = 0°$

- Case 2: Object launched from origin, with $\theta \neq 0°$

- Case 3: Object launched from height, with $\theta \neq 0°$



6.2 Case 1 Equations

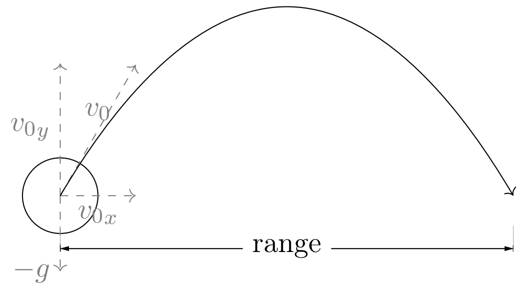
$$V_0 = V_{0x} \tag{18}$$

$$Y = -\left(\frac{V_y}{2}\right)t \tag{19}$$

$$Y = -\frac{1}{2}(9.81)t^2 \tag{20}$$

$$V_y^2 = 2(9.81)Y \tag{21}$$

$$V_y = (-9.81)t \tag{22}$$



6.3 Case 2 Equations

$$V_{0x} = V_x \tag{23}$$

$$X = V_{0x} \cdot t \tag{24}$$

$$X = V_0 \cos\theta \cdot t \tag{25}$$

$$Y = \frac{V_y + V_{0y}}{2} \cdot t \tag{26}$$

$$Y = V_0 \sin\theta \cdot t - \frac{1}{2}(9.81)t^2 \tag{27}$$

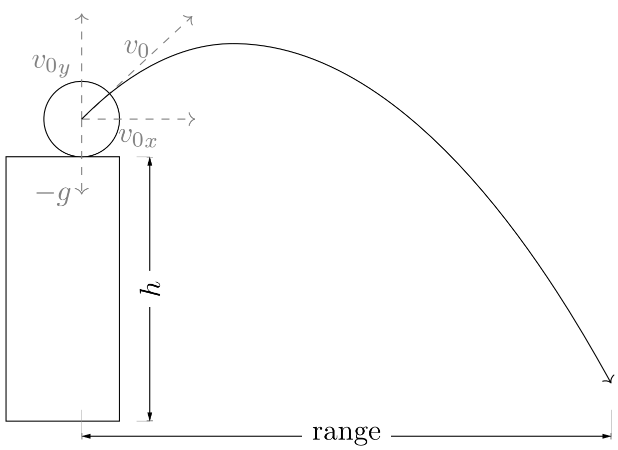
$$V_y = V_0 \sin\theta - (9.81)t \tag{28}$$

$$V_y^2 - V_{0y}^2 = 2(-9.81) \cdot Y \tag{29}$$

$$X_{max} = \frac{V_0^2 \sin(2\theta)}{9.81} \tag{30}$$

$$\text{Flight Time} = \frac{2 \cdot V_0 \sin\theta}{9.81} \tag{31}$$

$$\frac{Y_{max}}{X_{max}} = \frac{\tan\theta}{4} \tag{32}$$



6.4 Case 3 Equations

$$Y = -V_0 \sin\theta \cdot t - \frac{1}{2}(9.81)t^2 \tag{33}$$

$$\theta = \frac{1}{2} \cdot \sin^{-1}\left(\frac{a_x}{V_0^2}\right) \tag{34}$$

7 Dynamics

A study of the forces acting on mass bodies, and the resultant motion

7.1 Forces

Force is an action exerted on an object which may change the objects state of rest of motion.

The Four Forces of the Universe:

- Strong Nuclear
  - Forces responsible for the binding of atomic nuclei
  - Relative strength: 1
- Weak Nuclear
  - Forces responsible for particle beta decay
  - Relative strength: 1.0×10^{-6}
- Electromagnetic
  - Forces between charged particles, and are responsible for attractions and repulsions of protons and electrons
  - Relative strength: 7.3×10^{-3}
- Gravitational
  - The force of attraction between all masses of the universe
  - Relative strength: 6.0×10^{-39}

7.2 Tension Equations

7.2.1 Equal Angles

$$T = \frac{mg}{2\sin\theta} \tag{35}$$

7.2.2 Different Angles

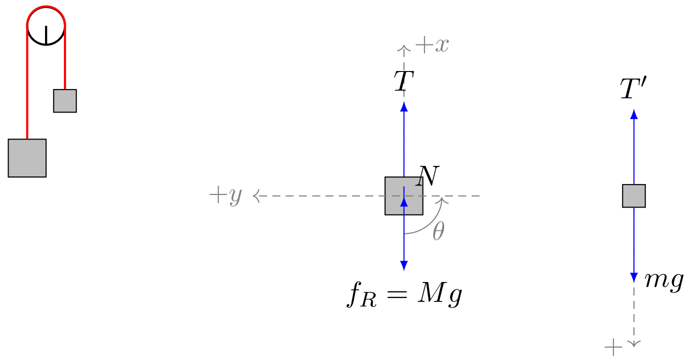
$$T_1 = \frac{mg}{\cos\theta_1 \tan\theta_2 + \sin\theta_1} \tag{36}$$

$$T_2 = \frac{mg}{\cos\theta_2 \tan\theta_1 + \sin\theta_2} \tag{37}$$

7.3 Atwood Machine

$$a = \frac{g(m_2 - m_1)}{m_1 + m_2} \tag{38}$$

Figure 3: Atwood Machine



7.4 Modified Atwood Machines

7.4.1 Block Pulled by Half of an Atwood Machine

$$a = \frac{m_2 g}{m_2 + m_1} \tag{39}$$

Same as below when $\theta = 0^\circ$

7.4.2 Block Pulled Up Incline by Half of Atwood Machine

$$a = \frac{m_2 g - m_1 g \sin\theta}{m_1 + m_2} \tag{40}$$

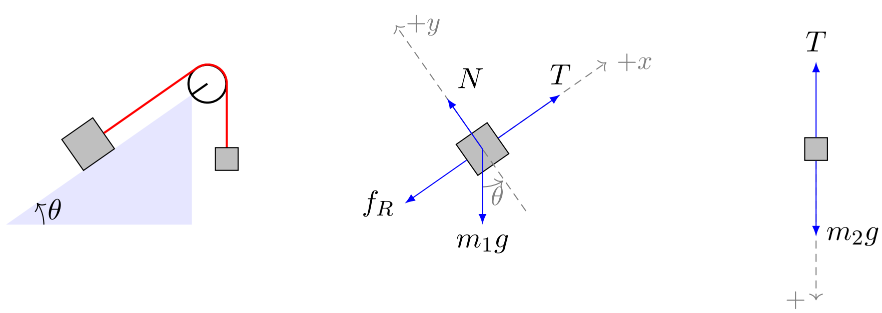


Figure 4: Inclined Atwood

7.4.3 Double Incline Plane Pulley Machine

$$a = \frac{m_2 g \sin\theta_2 - m_1 g \sin\theta_1}{m_2 + m_1} \tag{41}$$

8 Friction

8.1 Terms

- Coefficient of Friction (μ) : The quantity that expresses the dependence of frictional forces on the particular surfaces in contact
- Normal Force (N): Upward force countering gravity
- Static Friction (K_s): A force that resists the initiation of sliding motion between two surfaces that are in contact and at rest
- Kinetic Friction (K_f): Force that opposes the movement of two surfaces that are in contact and are sliding over each other.

*For any given mass, $K_s > K_f$

8.2 Normal Force

The Normal force[6] is a force opposing the downward force of gravity, and is explained by Newton's Third Law[7]. The Normal force is the negative force of gravity in the direction perpendicular to the surface, and can be calculated using component vector equations

8.3 Friction Equations

8.3.1 Friction Coefficient Formula

Below are common formulas used to calculate the force of friction. [8]

$$F_k = \mu_k N \tag{42}$$
$$F_s = \mu_s N \tag{43}$$

F_k = kinetic friction force
F_s = static friction force

8.3.2 Force with Friction Equation

$$F - \mu_k mg = ma \tag{44}$$

8.3.3 Diagonal Force with Friction

$$\Sigma F_y = F \sin\theta \tag{45}$$
$$N = mg + F_y \tag{46}$$
$$\Sigma F_x = ma \tag{47}$$
$$F_x - f_s = ma \tag{48}$$

6. Also shortened to F_n or N in physics equations
7. Where every action has a reaction equal in magnitude and opposite in direction
8. Easily remembered as *"Physics is FuN" [F = μN]*

When downward force[9]:

$$F\cos\theta - \mu(mg + F\sin\theta) = ma \tag{49}$$

When upward force (or downward force when using negative θ):

$$F\cos\theta - \mu(mg - F\sin\theta) = ma \tag{50}$$

8.3.4 Mass on an Incline with Friction

$$mg_x - F_k = ma \tag{51}$$

$$g\sin\theta - \mu_k N = ma \tag{52}$$

$$g\sin\theta - \mu_k mg\cos\theta = ma \tag{53}$$

If $a < 0$, the object will not move.

8.4 Hockey Puck Equation[10]

$$a = \mu_k \cdot g$$

If g is positive, use $a = -\mu_k \cdot g$

8.4.1 Acceleration of Half Atwood Machine with Friction

See equation 39 for equation without friction

$$\frac{m_2 g - \mu_k m_1 g}{m_2 + m_1} \tag{54}$$

8.4.2 Acceleration of Half Incline Atwood Machine with Friction

See equation 40 for equation without friction

$$a = \frac{m_2 g - m_1 g\sin\theta - \mu_{k_1} m_1 g\cos\theta}{m_2 + m_1} \tag{55}$$

8.4.3 Acceleration of Double Incline Atwood Machine with Friction

See equation 41 for equation without friction

$$a = \frac{m_2 g\sin\theta_2 - m_1 g\sin\theta_1 - \mu_{k_1} m_1 g\cos\theta_1 - \mu_{k_2} m_2 g\cos\theta_2}{m_2 + m_1} \tag{56}$$

9. Downward Force is also known as *"Elbow Grease"*, If someone asks you to put elbow grease into something, draw a freebody diagram of this concept and they will never speak to you again.
10. "Methacton graduates from Brown University, physics (sic), they just (rings bell) get it" - Robert Helm, 2016

8.5 Common Friction Coefficients

Table 1: Friction Coefficients

Surface	μ_s	μ_k
Rubber/Concrete	1.0	0.86
Steel/Concrete	0.74	0.57
Wood/Wood	0.35	0.20
Ice/Ice	0.10	0.03

*Note that $F_s = \mu_s \cdot N$
where $N =$ the normal force

9 Circular Motion

9.1 Centripetal Force Equation

$$F_c = \frac{mv^2}{r} \tag{57}$$

9.2 Centripetal Acceleration

$$a_c = \frac{V_t^2}{r} \tag{58}$$

Where V_t = tangential speed [m/s]

9.3 Tangental Acceleration

$$a_t = \alpha r \tag{59}$$

*Where α = angular acceleration $\left[\text{rad/s}^2\right]$

9.4 Friction Rotational Force Equation[11]

$$V^2 = r\mu_s g \tag{60}$$

9.5 Banked Curve Equation

9.5.1 Without Friction

$$V^2 = rg \cdot \tan\theta \tag{61}$$

9.5.2 With Friction

$$V^2 = \frac{\tan\theta + \mu_s}{1 - \mu_s \tan\theta} \cdot rg \tag{62}$$

9.6 Vertical Circle with Non-Uniform Speed

$$T = m \cdot \left[\frac{v^2}{r} + g\cos\theta\right] \tag{63}$$

9.7 Tension of Circle

9.7.1 Tension at Bottom

$$T_b = \frac{mv_b^2}{r} + mg \tag{64}$$

9.7.2 Tension at Top

$$T_t = \frac{mv_t^2}{r} - mg \tag{65}$$

9.8 Force Factor

$$\frac{F_{seat}}{mg} \tag{66}$$

11. Easily remembered as the "Rug equation" [$V^2 = r\mu_s g$]

9.9 Critical Velocity

Assuming $T_{top} = 0$, then:

$$V_{top} = \sqrt{rg} \tag{67}$$

10 Gravitational Forces

10.1 Law of Universal Gravitation

$$F_g = G\tfrac{m_1 m_2}{r^2} \tag{68}$$

G[12] is the ***universal gravitational constant***[13], equal to $6.673 \times 10^{11}\ \frac{\mathrm{N\,m^2}}{\mathrm{kg^2}}$.

10.2 Acceleration of Gravity at Given Height Above Earth's Surface

$$g = \frac{G \cdot m_2}{(r+h)^2} \tag{69}$$

10.3 Satellite Equation

$$V^2 = \frac{G \cdot m_2}{r} \tag{70}$$

m_2 is the mass of the planet.

12. Remember that ya homie Cap G will always be the same, while little g can change.
13. The Universal Gravitational Constant is like the secret ingredient of the giant soup that is the universe, and nobody can find the chef to ask him what or why it is.

11 Torque / Rotary Motion

*All angles θ in this section are in radians [rad], unless otherwise noted.

11.1 Common Variables

θ = Angular Displacement [rad]
ω = Angular Velocity [rad/s]
α = Angular Acceleration $[\text{rad/s}^2]$
τ = Torque [N m]
r = Radius [m]

11.2 Angular Displacement

$$\Delta\theta = \theta_f - \theta_i \tag{71}$$

11.3 Instantaneous Angular Speed

$$\theta = \omega \cdot t \tag{72}$$

11.4 Repackaged Motion Equations

$$\omega = \omega_0 + \alpha t \tag{73}$$
$$\theta = \omega_0 t + \frac{1}{2}\alpha t^2 \tag{74}$$
$$\omega^2 = \omega_0^2 + 2\alpha\theta \tag{75}$$
$$\theta = \left(\frac{\omega + \omega_0}{2}\right) \cdot t \tag{76}$$
$$\tag{77}$$

11.5 Converting to Common Kinetic Values

$$s = \theta \cdot r \tag{78}$$
$$v = \omega \cdot r \tag{79}$$
$$a = \alpha \cdot r \tag{80}$$

11.6 Torque Equation

$$\tau = F \cdot r = I\alpha \tag{81}$$

F = tangential force at radius r
r = radius from center

11.7 Inertia Formulas

Hoop or Thin Cylindrical Shell	$I_{CM} = m \cdot r^2$	(82)
Point Mass	$I_{CM} = m \cdot r^2$	(83)
Solid Disk	$I_{CM} = \frac{1}{2} \cdot m \cdot r^2$	(84)
Hollow Cylinder	$I_{CM} = \frac{1}{2} \cdot m \cdot (r_1^2 + r_2^2)$	(85)
Long Thin Rod with Rotational Axis Through Center	$I_{CM} = \frac{1}{12} \cdot m \cdot l^2$	(86)
Long Thin Rod with Rotational Axis Through End	$I_{CM} = \frac{1}{3} \cdot m \cdot l^2$	(87)
Solid Sphere	$I_{CM} = \frac{2}{5} \cdot m \cdot r^2$	(88)
		(89)

11.8 Dropping Mass from Fixed Point on Disk

$$a = \frac{m_2 g}{\frac{1}{2} m_{disk} + m_2} \tag{90}$$

11.9 Atwood Machine with Rotational Inertia

$$a = \frac{(m_1 - m_2)g}{\frac{I_{CM}}{R^2} + (m_1 + m_2)} \tag{91}$$

This will be used in our conservation of energy unit.

11.10 Double Atwood Machine with Rotational Inertia

$$a = \frac{g(m_1 - m_2)}{(m_1 + m_2 + m_{disk}} \tag{92}$$

12 Energy

12.1 Forms of Energy

All forms of energy can be placed into two basic categories:

- Kinetic: Energy in motion
- Potential: Stored energy

These broad categories can be split into other forms of energy

Forms of Kinetic Energy

- Motion
- Sound
- Thermal
- Electromagnetic Radiation
- Electrical

Forms of Potential Energy

- Gravitational
- Chemical
- Nuclear
- Elastic / Spring

12.2 Kinetic Energy

$$KE = \frac{1}{2} \cdot m \cdot v^2 \tag{93}$$

12.3 Potential Energy

$$PE = m \cdot g \cdot h \tag{94}$$

12.4 Work-Kinetic Energy Theorem

Net work done by all forces acting on the object is equal to the object's change in Kinetic energy

$$W_{net} = \Delta KE \text{ (net work)} \tag{95}$$

12.5 Elastic Potential Energy

Also called Spring Energy ($SE = PE_{elastic}$)

$$PE_{elastic} = \frac{1}{2}kx^2 \tag{96}$$

$k =$ spring constant (measures resistance of spring to stretch/compress) [N/m]
$x =$ distance compressed or stretched [m]

12.6 Rotational Energy

$$RE = \frac{1}{2} \cdot I \cdot \omega^2 \tag{97}$$

12.7 Mechanical Energy

Sum of kinetic energy and all forms of potential energy

$$ME = KE + \sum PE \tag{98}$$

12.8 Conservation of Energy

$$KE_1 + PE_1 = KE_2 + PE_2 \tag{99}$$

12.9 Sphere rolling down surface

See B1 for derivation

$$gh = \frac{7}{10}v^2 \tag{100}$$

12.9.1 Unknown Formula

$$h = d \sin\theta \tag{101}$$

12.10 Rotational Inertia of Sahas

$$\frac{V_o^2}{2\mu_k g} = d \tag{102}$$

12.11 Pendulum Equations

$h =$ height of mass in pendulum

$$2g(h_1 - h_2) = v^2 \tag{103}$$

$$2gr(1 - \cos\theta) = v^2 \tag{104}$$

$$h = r(1 - \cos\theta) \tag{105}$$

12.12 Roller Coaster Height[14]

$$h = \frac{5r}{2} \tag{106}$$

12.13 El Poder[15]

$$P = \frac{W}{\Delta t} \tag{107}$$

$$P = F \cdot v \tag{108}$$

12.14 Energy of Atwood Machine

$$m_2 gh = \frac{1}{2} m_2 v^2 + m_1 gh + \frac{1}{2} m_1 v^2 \tag{109}$$

14. Lowest possible height for a ball to roll through a loop while never leaving the track.
15. Español para power

13 Momentum

13.1 Definition of Momentum

Linear Momentum

$$\vec{p} = m \cdot \vec{v} \tag{110}$$

Angular Momentum

$$L = I\omega \tag{111}$$

*Momentum is measured in $kg \cdot m \cdot s^{-1}$

13.2 Law of Conservation of Momentum

The total momentum of all objects interacting with one another remains constant regardless of the nature of forces between the objects.

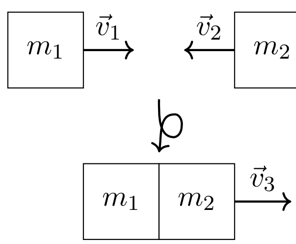


Figure 5: Inelastic Collision (Section 14.3)

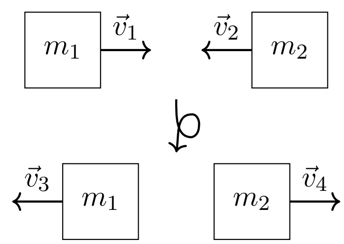


Figure 6: Elastic Collision (Section 14.4)

$$m_1v_1 + m_2v_2 = (m_1 + m_2)v_3$$ [16]

$$m_1v_1 + m_2v_2 = m_1v_3 + m_2v_4$$ [17]

$$v_3 = \left(\frac{m_1 - m_2}{m_1 + m_2}\right) v_1 + \left(\frac{2m_2}{m_1 + m_2}\right) v_2$$

$$v_4 = \left(\frac{2m_1}{m_1 + m_2}\right) v_1 + \left(\frac{m_2 - m_1}{m_1 + m_2}\right) v_2$$

14 Cannon Muzzle Velocity

$$V_1 = \frac{(m_1 + m_2)\sqrt{2\mu_k \cdot g \cdot d}}{m_1} \tag{112}$$

14.1 Impulse

$$I = m \cdot \Delta v \tag{113}$$

$$F \cdot \Delta t = m \cdot \Delta v \tag{114}$$

14.2 Impulse Momentum Theorem

$$F\Delta t = \Delta p = mv - mv_0 \tag{115}$$

14.3 Inelastic Collisions

Perfectly Inelastic Collisions are collisions which objects stick together after colliding and move together as one mass

Explosion/ Recoil equations:

$$(m_1 + m_2)v_3 = m_1 v_1 + m_2 v_2 \tag{116}$$

$$0 = m_1 v_1 + m_2 v_2 \tag{117}$$

14.4 Elastic Collision

Perfectly elastic collisions are collisions in which the total momentum and the total kinetic energy are conserved

$$m_1 v_1 + m_2 v_2 = m_1 v_3 + m_2 v_4 \tag{118}$$

$$V_3 = \left(\frac{m_1 - m_2}{m_1 + m_2}\right) V_1 + \left(\frac{2m_2}{m_1 + m_2}\right) V_2 \tag{119}$$

$$V_4 = \left(\frac{2m_1}{m_1 + m_2}\right) V_1 + \left(\frac{m_2 - m_1}{m_1 + m_2}\right) V_2 \tag{120}$$

14.5 Muzzle Velocity of Inelastic Ballistic Collision

$$V_1 = \frac{(m_1 + M_2)\sqrt{2\mu_k \cdot g \cdot d}}{m_1} \tag{121}$$

14.6 Ballistic Pendulum

$$\tfrac{1}{2} \cdot (v_3)^2 = g \cdot r(1 - \cos\theta) \tag{122}$$

14.7 Inelastic T-Bone Collision

$$m_A \cdot v_A = (m_A + m_B) \cdot v_3 \cdot \cos\theta \tag{123}$$

$$m_B \cdot v_B = (m_A + m_B) \cdot v_3 \cdot \sin\theta \tag{124}$$

*Where m_A is the horizontal car and m_B is the vertical car

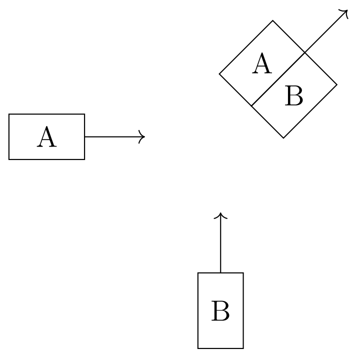


Figure 7: Inelastic T-Bone Collision

14.8 Elastic Glancing Collision (Pool)

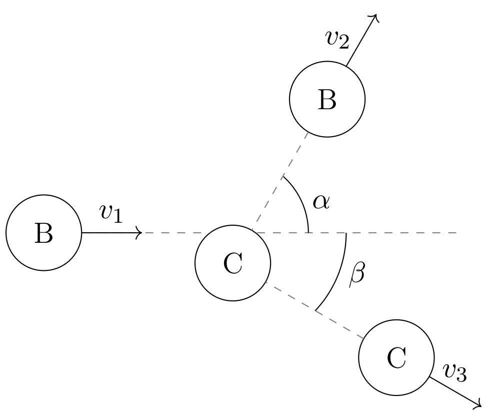


Figure 8: Elastic Pool Ball Collision

m_c : Cue Ball

m_b : Pool Ball

$$v_4 = v_1 \cos\beta \tag{125}$$

$$v_4 = v_1 \sin\theta \tag{126}$$

$$v_3 = v_1 \cos\theta \tag{127}$$

$$v_3 = v_1 \sin\beta \tag{128}$$

$$\cos\theta = \frac{v_3}{v_1} \tag{129}$$

15 Oscillations

15.1 Terms

- Oscillation: Movement back and forth at a constant speed
- Period: The time required for two successive wave crests to pass a fixed point (measured in seconds)
- Frequency: Amount of vibrations or wave cycles done in a given amount of time (measured in $\frac{1}{s} = \text{Hz}$)
- Restoring Force: A force that pulls the system to stay in equilibrium
- Simple Harmonic Oscillator: The path that an oscillation will follow F is the only force acting on the system, then the wave a sinusoidal path[18]

15.2 Hooke's Law:

$$F = -k \cdot x \tag{130}$$

**where k is a constant of spring stiffness, and x is the amplitude of the path of motion*

15.3 Velocities at Various Spring Positions

Assume a Simple Harmonic Oscillation path of a spring

The most constricted point of motion is position A
The most extended point of motion is position $-A$
The middle of these two points is position 0

- At positions A and $-A$, $v = KE = 0$, while PE is at its max
- At position 0, $PE = 0$, while v and KE are at max

15.4 Oscillation Motion Equations

$$T = 2\pi\sqrt{\frac{m}{k}} \tag{131}$$

$$x = A\cos\left(\frac{2\pi t}{T}\right) \tag{132}$$

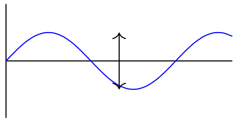
$$V_x = V_{max}\sqrt{1 - \frac{x^2}{A^2}} \tag{133}$$

$$\frac{kA^2}{m} = V_{max}^2 \tag{134}$$

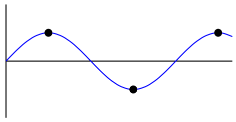
**where t is the fractional T value which corresponds to the object's position in the wave*

18. shortened to SHO, fo sho

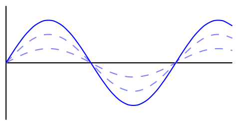
16 Waves/Optics



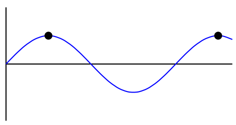
Amplitude - the magnitude of change over a period



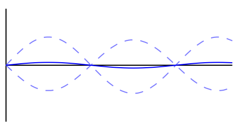
Antinode - Points on a wave with maximum amplitude



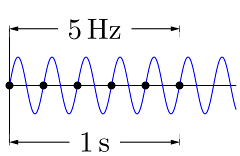
Constructive Interference - The interference of two waves leading to a single wave with double the amplitude



Crest - The maximum point of an oscillator

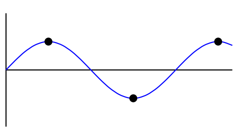


Destructive Interference - The interference of two opposite waves leading to cancellation

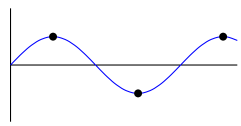


Frequency - Cycles per second

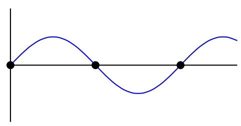
Longitudinal wave - A wave with displacement in the direction of the wave's movement.



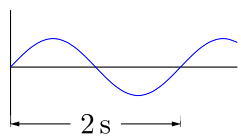
Mechanical wave - Oscillation of matter which transfer energy through a medium.



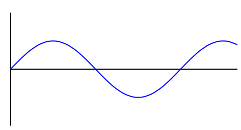
Medium - The substance through which waves travel.



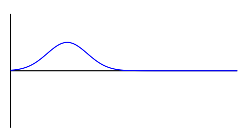
Node - The position of minimum displacement in a 3 standing wave system



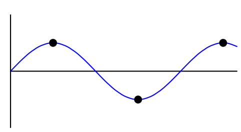
Period - The duration of a single cycle in a oscillator



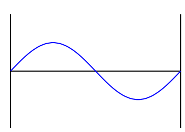
Periodic wave - A periodic function of 1D space that moves with constant time



Pulse wave - Non-sinusoidal waveform

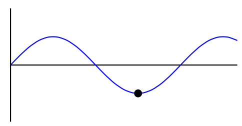


SHO - Simple Harmonic Oscillator is an oscillator with a restoring force proportional to the distance from the center.

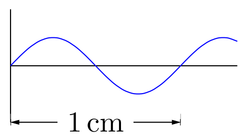


Standing wave - A wave that remains fixed in one location.

Transverse wave - A wave that vibrates perpendicularly to the direction of movement.



Trough - The lowest points on a wave.



Wavelength - The physical length of one wave.

16.1 Wave Equations

$$\text{Pulse equation:} y = \frac{A}{(x - vt)^2 + 1} \tag{135}$$

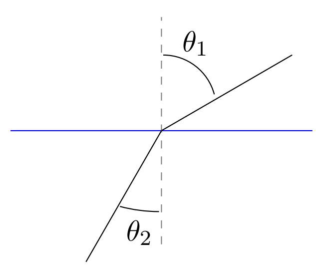
16.2 The Doppler Effect

$$f' = f \frac{v}{v \pm v_s} \tag{136}$$

- f' is observed frequency
- f is frequency at propogation
- v is velocity of wave in medium
- v_s is velocity of source

16.3 Snell's Law

$$n_1 \sin(\theta_1) = n_2 \sin(\theta_2) \tag{137}$$



16.4 Lens Makers Equations

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \tag{138}$$

$$m = |\frac{d_i}{d_o}| \tag{139}$$

$$m = |\frac{h_i}{h_o}| \tag{140}$$

$$m = |\frac{w_i}{w_o}| \tag{141}$$

d_o = Object Distance
d_i = Image Distance
f = Focal Length
m = Magnification

17 Statics and Magentism

Public Lorem static void ipsum$_{static}$

17.1 Statics

The study of stationary charges.
Like charges will repel each other and unlike charges will attract each other

$$C = c\frac{-q_1 \times q_2}{r^2} \tag{142}$$

Proton Positively charged molecule with mass of 1 AMU

Neutron Neutrally charged molecule with mass of 1 AMU

Electron Negatively charged molecule with mass of 0 AMU

Coulomb (C) Unit of charge

Charge of an Electron $\mathrm{e}^- = -1.602 \times 10^{-19}\,\mathrm{C}$

Charge of a Proton $\mathrm{P} = 1.602 \times 10^{-19}\,\mathrm{C}$

17.2 Coulomb's Law

$$F_{\text{electric}} = \frac{K_C \cdot q_1 \cdot q_2}{r^2} \tag{143}$$

$\mathrm{K} = 9.00 \cdot 10^9$

17.3 Polarization

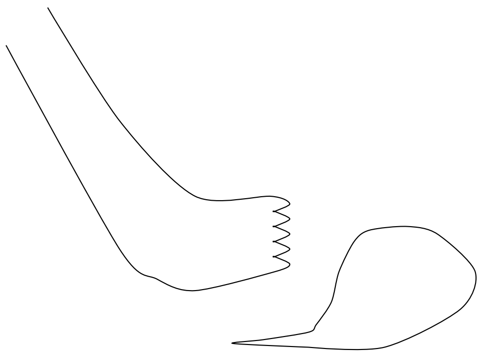
If a positively or negatively charged medium is placed near a molecule, it forces the electrons either away or toward the side facing the medium.[19]

17.3.1 Visual AIDS

Figure 9: Visualization of Dr. Helm's Electron Displacement Principle

19. As Dr. Robert Helm theorized, "electrons being displaced in an atom is just like how when you step on a balloon, it sorta deforms"

17.3.2 Artist Interpretation of Helm Displacement Principle



17.4 Electric Field Strength

An electric field is a region where an electric force on a test charge can be detected.
The SI unit of an electric field E is Newtons/Coulomb (N/C)
The direction of the vector $\hat{E}$ is the direction of the force.

17.5 Electricity and Magnetism

$$W = q \cdot V \tag{144}$$
$$V = E \cdot d \tag{145}$$
$$q = C \cdot V \tag{146}$$
$$C = K \cdot E_0 \cdot \frac{A}{d} \tag{147}$$

q = Electric Charge
F = Electric Force
E = Electric Field
V = Electric Potential
E_o = Permitivity of the Medium

18 Circuits

18.1 Current Charge and Movement

$$I = \frac{\Delta Q}{\Delta t} \tag{148}$$

$$I = Current$$
$$\Delta Q = \Delta Charge$$
$$\Delta T = \Delta Time$$

18.2 Resistance to Current

$$R = \frac{\Delta V}{I} \tag{149}$$

$$R = Resistance$$
$$\Delta V = \Delta ElectricPotential$$
$$I = Current$$

18.3 Voltage

$$V = I \cdot R \tag{150}$$

18.4 Resistance By a Wire

$$R = \rho \cdot LA \tag{151}$$

$$R = Resistance(ohms)$$
$$\rho = Resistivity$$
$$L = Length(cm)$$
$$A = Area(cm^2)$$

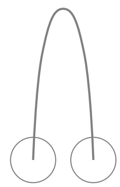
18.5 Resistors in Series

$$R_{eq} = R_1 + R_2 + R_3 + ... \tag{152}$$

18.6 Resistors in Parallel

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ... \tag{153}$$

19 Important Visual AID(S)



Acknowledgments

We would like to acknowledge Mr. Helm for his excellent teaching and insightful comments on physics.
We would also like to acknowledge Dhruv Sringari[20] for acknowledging this paper[21].

20. Dhruv Sringari did not help, in any way, shape, or form in the creation of this "beautiful paper" (Quote (*sic*)) Dhruv Sringari, Sept. 2016.
21. This paper, which Dhruv Sringari has accepted, through an undeniable statement, though this statement has not been recorded in any way, nor is able to be proven to any extent or by any action, as a superior object than anything that he has or will see, or that he has or will create, or that he has been or will be.

Appendix A.

$$S_{A_{H_{A_S}}} P^{L^S}$$

$$C_{H_{E_{E_{K_Y}}}} {}_{M}{}^{O^{N^{E^Y}}}$$

$$\Sigma_{\Sigma_{\Sigma_{\Sigma_\Sigma}}}$$

Appendix B. (Derivations)

In this appendix we will show derivations for the motion equations:

.1 Derivation for sphere rolling down surface

$$PE = KE + RE \tag{B1}$$

$$mgh = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 \tag{B2}$$

$$gh = \frac{7}{10}v^2 \tag{B3}$$

Appendix C.

In this appendix we will provide sample problems to review skills learned over this course

1. Assume an arbitrary man and woman. Let said man x = Fred and woman y = Jen, where Fred $\neq$ Fred Flintstone. How many carrots can Jared buy, and what effects will this have on the earth's orbit in reference to the sun?

References

Robert Helm. Robert Helm's Honors Phisics Course, 2016-2017.