PHYS 1303

SOLVING PHYSICS PROBLEMS

Many students, even if they are good at other sciences, math, or engineering, often find physics problems very difficult because they do not adopt the right approach for physics. Physics consists of a very small number of conceptually-deep basic laws that are combined with mathematical methods to solve problems in the real world; no other subject works like this. Physics problems are like mystery stories - you often don't know who dunnit until the very end.

- Don't search for "the right equation". You will not be able to solve a real physics problem by finding an appropriate equation and then plugging numbers into it. No self-respecting college-level teacher would assign such a problem.

- **Don't memorize.** In physics you should not need to memorize anything (equations for basic laws should be available in your book or on a formula sheet) and it will not help you solve problems. It is important you understand the meaning of equations that express basic laws, and memorization usually indicates a simple lack of this conceptual understanding.

Below is a more detailed format it is suggested you use when solving *all* physics problems, even if you are sure you know how to get the answer. This skill will help you to solve physics problems and also to explain your solution to a reader (who may be the grader, yourself 2 months later, or the Nobel Prize committee).

DIANA

DESCRIPTION/ **D**IAGRAM – define unique symbols for unknowns sought and data given, label a diagram with your symbols, include a directed coordinate system, a few words to clarify perhaps.

IDEA – state the fundamental idea(s) or principle(s) of physics you will use. This can be expressed via an equation chosen from the formula sheet. You should then write it out explicitly for the current problem using your symbols (don't just write numbers immediately).

ANALYSIS – symbolically derive the unknown you want using algebra and calculus

NUMBERS – substitute data for the knowns and perform calculation of the unknown

ANSWER – check number makes sense, round to appropriate precision, put units

For more detailed advice about how to approach physics problems, see Dan Styler's page http://www.oberlin.edu/physics/dstyer/SolvingProblems.html

Grading Scheme Explanation

Each check mark is worth one point. The grader may sometimes mark an X or circle something wrong or they may offer advice in brackets; all this is for information only.

Check marks are embellished in 3 ways:

1. Diagram and/or Description (D) – see above
2. Method (M) - This is for *any valid* Method that forms part of the Idea or Analysis steps.
3. Answer (A) - This is for the correct final Answer, including units and appropriate precision.You will lose ½ point on an Answer (A) if either of the following occurred:
   a) wrong units b) inappropriate precision (you cannot lose more than one ½ point due to precision on the test.)

Carry Through Error (CTE) - an incorrect Answer (A) or diagram (D) *may* be awarded the points if it resulted from the use of a previous erroneous answer. The directly preceding method (M) points must have been awarded and the previous erroneous answer should not have simplified the problem. CTE points are awarded at the discretion of the grader.

Exemplary Solutions

Chap 1 Problem. To an appropriate number of significant figures for the data given, how many U.S. gallons of gasoline are in one litre?
[1 U.S. gallon = 231 in^3, $1\,L = 10^{+3}\ cm^3$ (exact definition), 1 in = 2.54cm]

Analysis (1 points)

$$1\ L = \frac{1\ L}{cm^3}\ \frac{cm^3}{in^3}\ \frac{in^3}{gal}\ gal$$

Numbers (1 point use of data)

$$= 10^3\,(2.54)^{-3}\ (231)^{-1}\ gal$$

$$= 0.26417\ gal$$

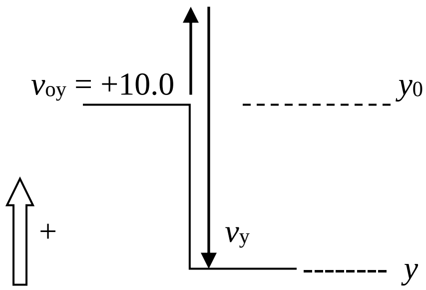
Answer (1 point)

$= \underline{\underline{0.264}}$ gal (2sf)

Chap 2 Problem. A stone is thrown from the top of a building with an initial velocity of 10.0 m/s upwards. The top of the building is 100 m (3sf) above the ground. What is the speed of impact?

[*Neglect air resistance and assume g = 9.80 m/s²*]

Diagram/Description (2 points)



a_y = - 9.80 m/s^2

$y - y_0$ = -100 m (change in y)

v_y velocity just before impact   it is <u>not</u> zero

Idea (1 point)

$v_y^2 = v_{0y}^2 + 2\, a_y\, (y - y_0)$ since constant acceleration

Analysis (no points)

$v_y = \sqrt{(\, v_{0y}^2 + 2\, a_y\, (y - y_0)\,)}$

Numbers (no points)

$= \sqrt{[10^2 + 2(-9.8)(-100)]}$

$= -\ 45.37$ negative root because up was chosen as positive

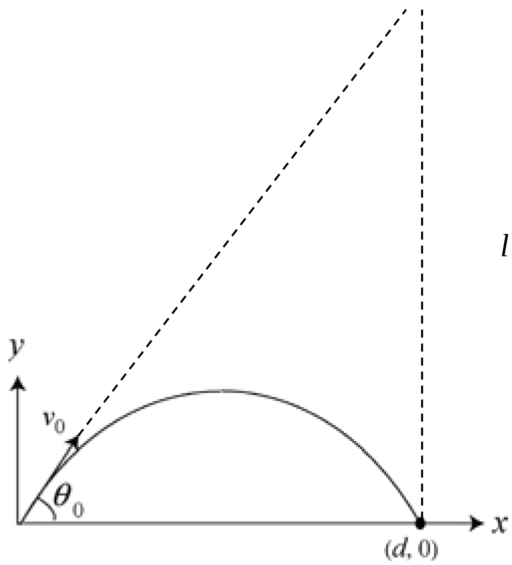
Answer (1 point)

speed = <u>45.4 m/s</u> (3sf) positive because speed is magnitude of velocity

Chap 4 Problem. A rifle that shoots bullets at 460 m/s is to be aimed at a target 45.7 m away. If the center of the target is level with the rifle, how high above the target must the rifle barrel be pointed so that the bullet hits dead center? [2 sin θ cos θ = sin 2θ]

Diagram/Description (2 points)

v_o = 460 m/s
$x - x_0 = d$ = 45.7 m
$a_x = 0$
a_y = - 9.80 m/s^2
$y - y_0 = 0$ (no change in y)



Idea (2 points)

$x - x_0 = v_{0x}\, t + ½\, a_x\, t^2$ $\quad d = v_0 \cos \theta_0\, t$ $\quad$ constant acceleration
$y - y_0 = v_{0y}\, t + ½\, a_y\, t^2$ $\quad 0 = v_0 \sin \theta_0\, t + ½\, a_y\, t^2$

$l = d \tan \theta_0$ $\quad$ trig right-angled triangle

Analysis (1 point)

$t = d / v_0 \cos \theta_0$
$0 = t\,(v_0 \sin \theta_0 + ½\, a_y\, t\,)$ $\quad$ cancel t = 0 solution (launch time).
$v_0 \sin \theta_0 = -\, ½\, a_y\, d / v_0 \cos \theta_0$ $\quad$ substitute for t
$\sin \theta_0 \cos \theta_0 = -\, ½\, a_y\, d / v_0^2$
$\theta_0 = ½ \sin^{-1} [\, -\, a_y\, d / v_0^2\,]$

Numbers (no points)

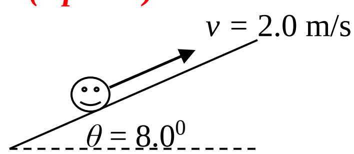
$= ½ \sin^{-1} [\, 9.80 \times 45.7 / 4 \times 460^2\,]$
$= 0.0606^o$
$l = 45.7 \tan 0.0606$
$= 0.484$

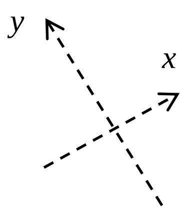
Answer (1 point)

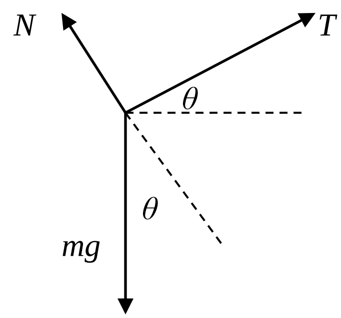
= <u>0.484 m</u> (3sf)

<u>Chap 5/6 Problem</u>. Holding on to a towrope moving parallel to a frictionless ski slope, a 50 kg skier is pulled up the slope, which is at an angle of 8.0° with the horizontal. What is the magnitude of the force on the skier from the rope when the magnitude v of the skier's velocity is $v = 2.0$ m/s as v increases at a rate of 0.10 m/s^2 ?

Diagram/Description (2 points)







N = normal force magnitude (unknown)
T = rope tension magnitude (required)
mg = gravity magnitude =50 x 9.8=490 N

$a_x = + 0.1$ m/s^2
$a_y = 0$
$v_x = 2.0$ m/s

Idea (1 point)

$\Sigma \underline{\boldsymbol{F}} = m\underline{\boldsymbol{a}}$
x: $T - mg \sin\theta = m\, a_x$
y: $N - mg \cos\theta = m\, a_y$

Numbers (no points)

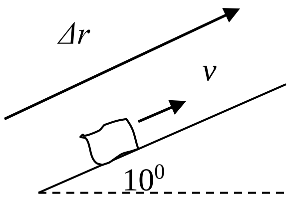
T = 50 x 9.80 x sin 8.0° + 50 x 0.1 v_x not needed
= 73.1948

Answer (1 point)

= <u>73 N</u> (2sf)

Chap 7 Problem. Boxes are transported from one location to another in a warehouse by means of a conveyor belt that moves with a constant speed of 0.50 m/s. At a certain location the conveyor belt moves for 2.0 m up an incline that makes an angle of 10° with the horizontal. Assume that a 2.0 kg box rides on the belt without slipping. At what rate is the conveyor belt doing work on the box?

Diagram/Description (1 point)



Box mass m = 2.0 kg
Box speed v = 0.50 m/s   constant
Box distance Δr = 2.0 m
Forces are static friction, normal, and gravity, all constant.
Friction and Normal are due to conveyor.

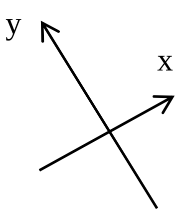
Idea (2 points)

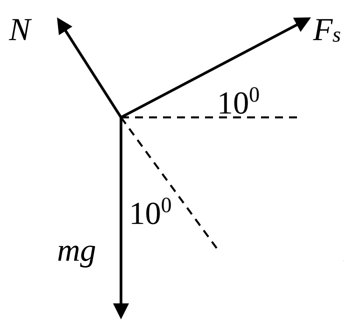
$W = \underline{\boldsymbol{F}} \bullet \underline{\boldsymbol{\Delta r}} = F\,\Delta r \cos\theta$

$P = W / \Delta t$

$v = \Delta r / \Delta t$ since constant velocity

Diagram/Description (1 point)





N = normal force magnitude (unknown)
F_s = static friction magnitude (unknown)
mg = gravity magnitude =2.0x9.8=19.6 N
$\underline{\boldsymbol{\Delta r}}$ in x direction

Idea (2 points)

Work done by N : $W = N\,\Delta r \cos 90^0 = 0$
Work done by F_s: $W = F_s\,\Delta r \cos 0^0 = F_s\,\Delta r$
$\Sigma F_x = ma_x = 0$ constant velocity
$+ F_s - mg \sin 10^0 = 0$

Algebra (no points)

$W = mg \sin 10^0 \Delta r$
$P = mg \sin 10^0 \Delta r / \Delta t$
$= mg \sin 10^0 \; v$

Numbers (points given in Description for use of data)

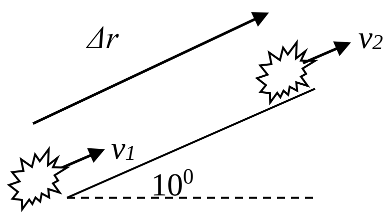
$= 19.6 \times \sin 10^0 \times 0.50$
$= 1.7017$

Answer (1 point)

= 1.7 W (2sf)

Chap 8 Problem A volcanic ash flow is moving across horizontal ground when it encounters a 10° upslope. The front of the flow then travels 920 m up the slope before stopping. Assume that the gases entrapped in the flow lift the flow and thus make the frictional force from the ground negligible, and ignore air resistance. What was the initial speed of the front of the flow?

Diagram/Description (1 point)



Ash mass m (unknown)
Ash intial speed v_1 (required)
Ash final speed $v_2 = 0$
Ash distance $\Delta r = 920$ m

Idea (2 points)

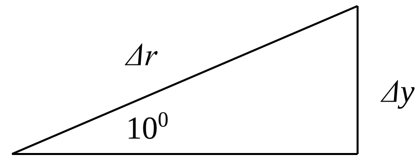
$\Delta E = \Delta K + \Delta U = 0$ mechanical energy conserved

$K_1 + U_1 = K_2 + U_2$

$\frac{1}{2} m v_1^2 + m g y_1 = \frac{1}{2} m v_2^2 + m g y_2$
$\frac{1}{2} m v_1^2 = + m g y_2 - m g y_1$

Diagram/Description (1 point)

$y_2 - y_1 = \Delta y$
$\Delta y / \Delta r = \sin 10^0$



Algebra (no points)

$\frac{1}{2} m\, v_1^2 = m\, g\, \Delta y$

$v_1^2 = 2\, g\, \Delta r \sin 10^0$

$v_1 = \sqrt{(2\, g\, \Delta r \sin 10^0)}$

Numbers (points given in Description for use of data)

$= \sqrt{(2 \text{ x } 9.8 \text{ x } 920 \sin 10^0)}$

$= 55.957$

Answer (1 point)

= <u>56 m/s</u> (2sf)

<u>Chap 9 Problem</u>. Two titanium spheres approach each other head-on with the same speed and collide elastically. After the collision, one of the spheres, whose mass is 300g, remains at rest. What is the mass of the other sphere?

Diagram/Description (1 point)

mass $m_1 = 0.300$ kg
mass m_2 required
initial speeds equal $v_{1i} = v_{2i}$
final speeds: $v_{1f} = 0$; v_{2f} unknown

→ + direction

Idea (2 points)

$\underline{\mathbf{p}}_{1i} + \underline{\mathbf{p}}_{2i} = \underline{\mathbf{p}}_{1f} + \underline{\mathbf{p}}_{2f}$ system linear momentum conserved

$+ m_1 v_{1i} - m_2 v_{1i} = + m_2 v_{2f}$

$K_{1i} + K_{2i} = K_{1f} + K_{2f}$ system kinetic energy conserved (elastic collision)

$\frac{1}{2} m_1\, v_{1i}^{\;2} + \frac{1}{2} m_2\, v_{1i}^{\;2} = \frac{1}{2} m_2\, v_{2f}^2$

Algebra (1 point)

Substitute for v_{2f}

$$v_{2f} = (m_1 - m_2)\, v_{1i} \;/\; m_2$$

$$\tfrac{1}{2} v_{1i}^{\,2}(m_1 + m_2) = \tfrac{1}{2} m_2 \,[(m_1 - m_2)\, v_{1i} \;/\; m_2]^2$$

$$(m_1 + m_2) = (m_1 - m_2)^2 / m_2$$ v_{1i} cancels, so value not needed.

$$m_2 m_1 + m_2^2 = m_1^2 - 2\, m_2 m_1 + m_2^2$$

$$0 = m_1 (\, m_1 - 3\, m_2)$$

$$m_1 = 3\, m_2$$ since $m_1 \neq 0$

Numbers (points given in Description for use of data)

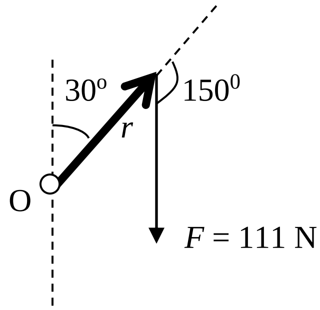
$m_2 = 0.300/3$
$= 0.100$

Answer (1 point)

= 100g (3sf)

Chap 10 Problem. The length of a bicycle pedal arm is 0.152 m and its mass is 0.35 kg. A downward force of 111 N is applied to the pedal by the rider. (a) What is the torque about the pedal arm's pivot when the arm is at angle 30° to the upward vertical? (b) What is the angular acceleration of the pedal arm at this time? (*assume the pedal arm is a thin uniform rod*)

Diagram/Description (2 points)



F applied at **r** produces a clockwise torque about O

r = 0.152 m
mass $m = 0.35$ kg

choose  + direction clockwise

a)

Idea (1 point)

Torque magnitude
$\tau = rF \sin \phi$

Numbers (points given in Description for use of data)

τ = 0.152 x 111 x sin 150°
= 8.436

Answer (1 point)

$\underline{\boldsymbol{\tau}}$ = $\underline{\underline{+\ 8.4\ \text{Nm}}}$ (2sf)

The + sign together with the clockwise convention chosen above are necessary for indicating the torque vector. Alternatively, by the right hand rule, the vector direction may be specified as "into the page".

b)

Idea (1 point)

$\tau = I\,\alpha$

$\underline{\boldsymbol{\tau}}$ and $\underline{\boldsymbol{\alpha}}$ same direction (I scalar)

$I = mr^2 / 3$

Formula for rotational inertia of a rod about one end. (Formula would be given to you in a test question.)

Algebra (no points)

$\alpha = \tau / I = 3\,\tau \;/\; mr^2$

Numbers (points given in Description for use of data)

α = 3 x 8.436 / (0.35 x 0.152^2)

= 3129

Use the unrounded value of τ calculated in part a), otherwise you make a rounding error on final answer.

Answer (1 point)

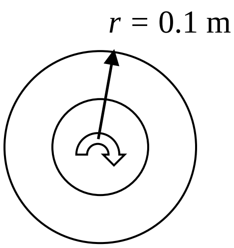
$\underline{\boldsymbol{\alpha}}$ = $\underline{+\ 3.1 \times 10^3\ \text{rad/s}^2}$ (2sf)

The + sign together with the clockwise convention chosen above are necessary for indicating the angular acceleration vector. Alternatively, by the right hand rule, the vector direction may be specified as "into the page".

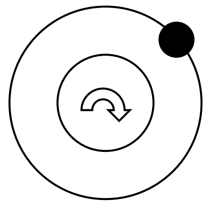
Chap 11 Problem. A horizontal vinyl record of mass 0.10 kg and radius 0.10 m rotates freely about a vertical axis through its center with an angular speed of 4.7 rad/s and a rotational inertia of 5.0 x 10^{-4} kgm^2. Putty of mass 0.020 kg drops vertically onto the record from above and sticks to the edge of the record. What is the angular speed of the record immediately afterwards?

Diagram/Description (1 point)

before



after



Treat putty as point mass m = 0.1 kg at radius r

record angular speed ω_i = 4.7 rad/s
record rotational inertia I_i = 5.0 x 10^{-4} kgm^2

Record/putty angular speed ω_f (required)
Record/putty rotational inertia I_f (unknown)

Idea (2 points)

$I_i \omega_i = I_f \omega_f$

$I_f = I_i + mr^2$

Algebra (no points)

$\omega_f = I_i \omega_i / I_f = I_i \omega_i / (I_i + mr^2)$

Numbers (points given in Description for use of data)

= 5.0 x 10^{-4} x 4.7 / (5.0 x 10^{-4} + 0.1 x 0.1^2)
= 1.5666

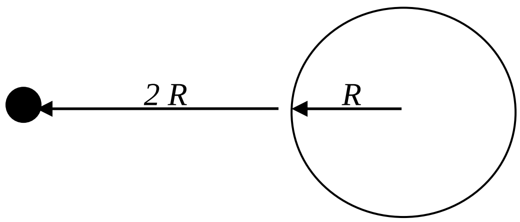
Answer (1 point)

= <u>1.6 rad/s</u> (2sf)

Chap 13 Problem. What is the magnitude of the free-fall acceleration at a point that is a distance 2*R* above the surface of the Earth, where *R* is the radius of the Earth and g = 9.80 m/s^2 at Earth's surface.

Diagram/Description (1 point)

Free-fall mass *m*



center to center distance = 3 R

Earth mass = M

Idea (2 points)

$G\,M\,m\,/\,(3R)^2 = m\,a$

$G\,M\,m\,/\,R^2 = m\,g$ mass *m* cancel out

Algebra (1 point)

Substitute for $GM\,/\,R^2 = g$
$a = GM\,/\,9R^2 = g\,/\,9$

Numbers (points given in Description for use of data)

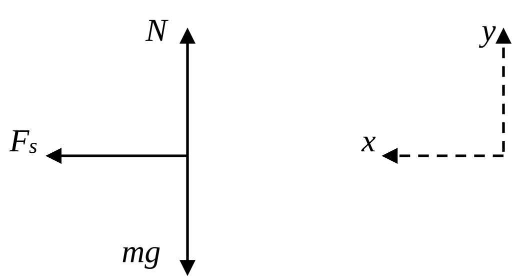
$a = 9.80/9$
$= 1.0888$

Answer (1 point)

= 1.09 m/s^2 (3sf)

Chap 15 Problem. A block is on a horizontal surface (a shake table) that is moving back and forth horizontally with simple harmonic motion of frequency 2.0 Hz. The coefficient of static friction between block and surface is 0.50. How great can the amplitude of the SHM be if the block is not to slip along the surface?

Diagram/Description (2 points)



SHM force from static friction F_s
F_s is max on verge of slipping,
occurs when when SHM a_x is max

$\mu_s = 0.5$
SHM frequency $f = 2.0$ Hz
SHM amplitude *A* required

Idea (3 points)

$F_s < \mu_s N$
$\Sigma \underline{\boldsymbol{F}} = m\underline{\boldsymbol{a}}$
x: $F_s = m\, a_x$
y: $N - mg = m\, a_y = 0$

$$x = A \cos (\omega t + \varphi)$$
$$a_x = d^2x/dt^2 = - A\omega^2 \cos (\omega t + \varphi)$$

$a_x \max = A\omega^2$

Analysis (no points)

$\mu_s N = ma_x \max$
$\mu_s mg = mA\omega^2$
$A = \mu_s g / \omega^2$
$= \mu_s g / (2\pi f)^2$

Numbers (points given in Description for use of data)

$= 0.50 \times 9.8 / (2 \times \pi \times 2.0)^2$
$= 0.0310296$

Answer (1 point)

= <u>0.031 m</u> (2sf)