INSTRUCTOR SOLUTIONS MANUAL

VOLUME 1

DOUGLAS C. GIANCOLI'S

PHYSICS PRINCIPLES WITH APPLICATIONS

7TH EDITION

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PREFACE

This *Instructor's Solutions Manual* provides answers and worked-out solutions to all end of chapter questions and problems from chapters 1 – 15 of *Physics: Principles with Applications*, *7th Edition*, by Douglas C. Giancoli. At the end of the manual are grids that correlate the 6th edition questions and problems to the 7th edition questions and problems.

We formulated the solutions so that they are, in most cases, useful both for the student and the instructor. Accordingly, some solutions may seem to have more algebra than necessary for the instructor. Other solutions may seem to take bigger steps than a student would normally take: e.g. simply quoting the solutions from a quadratic equation instead of explicitly solving for them. There has been an emphasis on algebraic solutions, with the substitution of values given as a very last step in most cases. We feel that this helps to keep the physics of the problem foremost in the solution, rather than the numeric evaluation.

Much effort has been put into having clear problem statements, reasonable values, pedagogically sound solutions, and accurate answers/solutions for all of the questions and problems. Working with us was a team of five additional solvers – Karim Diff (Santa Fe College), Thomas Hemmick (Stony Brook University), Lauren Novatne (Reedley College), Michael Ottinger (Missouri Western State University), and Trina VanAusdal (Salt Lake Community College). Between the seven solvers we had four complete solutions for every question and problem. From those solutions we uncovered questions about the wording of the problems, style of the possible solutions, reasonableness of the values and framework of the questions and problems, and then consulted with one another and Doug Giancoli until we reached what we feel is both a good statement and a good solution for each question and problem in the text.

Many people have been involved in the production of this manual. We especially thank Doug Giancoli for his helpful conversations. Karen Karlin at Prentice Hall has been helpful, encouraging, and patient as we have turned our thoughts into a manual. Michael Ottinger provided solutions for every chapter, and helped in the preparation of the final solutions for some of the questions and problems. And the solutions from Karim Diff, Thomas Hemmick, Lauren Novatne, and Trina VanAusdal were often thought-provoking and always appreciated.

Even with all the assistance we have had, the final responsibility for the content of this manual is ours. We would appreciate being notified via e-mail of any errors that are discovered. We hope that you will find this presentation of answers and solutions useful.

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1

INTRODUCTION, MEASUREMENT, ESTIMATING

Responses to Questions

1. (*a*) A particular person's foot. Merits: reproducible. Drawbacks: not accessible to the general public; not invariable (size changes with age, time of day, etc.); not indestructible.

   (*b*) Any person's foot. Merits: accessible. Drawbacks: not reproducible (different people have different size feet); not invariable (size changes with age, time of day, etc.); not indestructible.

   Neither of these options would make a good standard.

2. The distance in miles is given to one significant figure, and the distance in kilometers is given to five significant figures! The value in kilometers indicates more precision than really exists or than is meaningful. The last digit represents a distance on the same order of magnitude as a car's length! The sign should perhaps read "7.0 mi (11 km)," where each value has the same number of significant figures, or "7 mi (11 km)," where each value has about the same % uncertainty.

3. The number of digits you present in your answer should represent the precision with which you know a measurement; it says very little about the accuracy of the measurement. For example, if you measure the length of a table to great precision, but with a measuring instrument that is not calibrated correctly, you will not measure accurately. Accuracy is a measure of how close a measurement is to the true value.

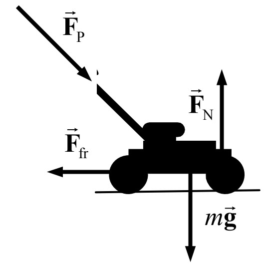
4. If you measure the length of an object, and you report that it is "4," you haven't given enough information for your answer to be useful. There is a large difference between an object that is 4 meters long and one that is 4 feet long. Units are necessary to give meaning to a numerical answer.

5. You should report a result of 8.32 cm. Your measurement had three significant figures. When you multiply by 2, you are really multiplying by the integer 2, which is an exact value. The number of significant figures is determined by the measurement.

6. The correct number of significant figures is three: $\sin 30.0° = 0.500$.

7. Useful assumptions include the population of the city, the fraction of people who own cars, the average number of visits to a mechanic that each car makes in a year, the average number of weeks a mechanic works in a year, and the average number of cars each mechanic can see in a week.

50. (*a*) We assume that the mower is being pushed to the right. $\vec{\mathbf{F}}_{\text{fr}}$ is the friction force, and $\vec{\mathbf{F}}_{\text{P}}$ is the pushing force along the handle.



(*b*) Write Newton's second law for the horizontal direction. The forces must sum to 0 since the mower is not accelerating.

$$\sum F_x = F_{\text{p}} \cos 45.0^\circ - F_{\text{fr}} = 0 \quad \rightarrow$$

$$F_{\text{fr}} = F_{\text{p}} \cos 45.0^\circ = (88.0\ \text{N}) \cos 45.0^\circ = \boxed{62.2\ \text{N}}$$

(*c*) Write Newton's second law for the vertical direction. The forces must sum to 0 since the mower is not accelerating in the vertical direction.

$$\sum F_y = F_{\text{N}} - mg - F_{\text{p}} \sin 45.0^\circ = 0 \quad \rightarrow$$

$$F_{\text{N}} = mg + F_{\text{p}} \sin 45^\circ = (14.0\ \text{kg})(9.80\ \text{m/s}^2) + (88.0\ \text{N}) \sin 45.0^\circ = \boxed{199\ \text{N}}$$

(*d*) First use Eq. 2–11a to find the acceleration.

$$v - v_0 = at \quad \rightarrow \quad a = \frac{v - v_0}{t} = \frac{1.5\ \text{m/s} - 0}{2.5\ \text{s}} = 0.60\ \text{m/s}^2$$

Now use Newton's second law for the *x* direction to find the necessary pushing force.

$$\sum F_x = F_{\text{p}} \cos 45.0^\circ - F_{\text{f}} = ma \quad \rightarrow$$

$$F_{\text{p}} = \frac{F_{\text{f}} + ma}{\cos 45.0^\circ} = \frac{62.2\ \text{N} + (14.0\ \text{kg})(0.60\ \text{m/s}^2)}{\cos 45.0^\circ} = \boxed{99.9\ \text{N}}$$

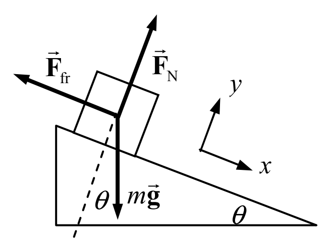
51. The average force can be found from the average acceleration. Use Eq. 2–11c to find the acceleration.

$$v^2 = v_0^2 + 2a(x - x_0) \quad \rightarrow \quad a = \frac{v^2 - v_0^2}{2(x - x_0)}$$

$$F = ma = m\left(\frac{v^2 - v_0^2}{2(x - x_0)}\right) = (60.0\ \text{kg})\left(\frac{0 - (10.0\ \text{m/s})^2}{2(25.0\ \text{m})}\right) = -120\ \text{N}$$

The average retarding force is $\boxed{1.20 \times 10^2\ \text{N}}$, in the direction opposite to the child's velocity.

52. (*a*) Here is a free-body diagram for the box at rest on the plane. The force of friction is a STATIC frictional force, since the box is at rest.

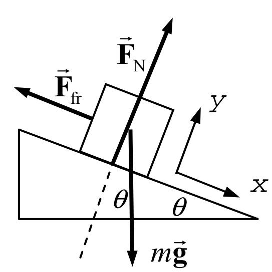


(*b*) If the box were sliding down the plane, the only change is that the force of friction would be a KINETIC frictional force.

(*c*) If the box were sliding up the plane, the force of friction would be a KINETIC frictional force, and it would point down the plane, in the opposite direction to that shown in the diagram.

Notice that the angle is not used in this solution.

53. A free-body diagram for the bar of soap is shown. There is no motion in the *y* direction and thus no acceleration in the *y* direction. Write Newton's second law for both directions, and use those expressions to find the acceleration of the soap.



$$\sum F_y = F_{\text{N}} - mg \cos \theta = 0 \quad \rightarrow \quad F_{\text{N}} = mg \cos \theta$$

$$\sum F_x = mg \sin \theta - F_{\text{fr}} = ma$$

$$ma = mg \sin \theta - \mu_{\text{k}} F_{\text{N}} = mg \sin \theta - \mu_{\text{k}} mg \cos \theta$$

$$a = g(\sin \theta - \mu_{\text{k}} \cos \theta)$$

We could also count "boxes" under the graph, where each "box" has an "area" of $(50\text{ N})(0.01\text{ s}) = 0.5\text{ N}\cdot\text{s}$. There are almost seven whole boxes and the equivalent of about three whole boxes in the partial boxes. Ten boxes would be about $\boxed{5\text{ N}\cdot\text{s}}$.

(*b*) The velocity can be found from the change in momentum. Call the positive direction the direction of the ball's travel after being served.

$$\Delta p = m\Delta v = m(v_f - v_i) \quad\rightarrow\quad v_f = v_i + \frac{\Delta p}{m} = 0 + \frac{5\text{ N}\cdot\text{s}}{6.0\times10^{-2}\text{ kg}} \approx \boxed{80\text{ m/s}}$$

24. (*a*) The impulse is the change in momentum. Take upward to be the positive direction. The velocity just before reaching the ground is found from conservation of mechanical energy.

$$E_{\text{initial}} = E_{\text{final}} \quad\rightarrow\quad mgh = \tfrac{1}{2}mv_y^2 \quad\rightarrow$$

$$v_y = \pm\sqrt{2gh} = \sqrt{2(9.80\text{ m/s}^2)(2.8\text{ m})} = 7.408\text{ m/s, down}$$

$$\vec{\mathbf{J}} = \Delta\vec{\mathbf{p}} = m(\vec{\mathbf{v}}_f - \vec{\mathbf{v}}_0) = (55\text{ kg})(0 - -7.408\text{ m/s}) = 407\text{ kg}\cdot\text{m/s} \approx \boxed{410\text{ kg}\cdot\text{m/s, upward}}$$

(*b*) The net force on the person is the sum of the upward force from the ground, plus the downward force of gravity.

$$F_{\text{net}} = F_{\text{ground}} - mg = ma \quad\rightarrow$$

$$F_{\text{ground}} = m(g+a) = m\left(g + \frac{(v_f^2 - v_0^2)}{2\Delta x}\right) = (55\text{ kg})\left((9.80\text{ m/s}^2) + \frac{0-(-7.408\text{ m/s})^2}{2(-0.010\text{ m})}\right)$$

$$= \boxed{1.5\times10^5\text{ N, upward}}$$

This is about 280 times the jumper's weight.

(*c*) We do this the same as part (*b*), but for the longer distance.

$$F_{\text{ground}} = m\left(g + \frac{(v_f^2 - v_0^2)}{2\Delta x}\right) = (55\text{ kg})\left((9.80\text{ m/s}^2) + \frac{0-(-7.408\text{ m/s})^2}{2(-0.5\text{ m})}\right)$$

$$= 3557\text{ N} \approx \boxed{4000\text{ N, upward}}$$

This is about 6.5 times the jumper's weight.

25. Let A represent the 0.440-kg ball and B represent the 0.220-kg ball. We have $v_A = 3.80\text{ m/s}$ and $v_B = 0$. Use Eq. 7–7 to obtain a relationship between the velocities.

$$v_A - v_B = -(v_A' - v_B') \quad\rightarrow\quad v_B' = v_A + v_A'$$

Substitute this relationship into the momentum conservation equation for the collision.

$$m_A v_A + m_B v_B = m_A v_A' + m_B v_B' \quad\rightarrow\quad m_A v_A = m_A v_A' + m_B(v_A + v_A') \quad\rightarrow$$

$$v_A' = \frac{(m_A - m_B)}{(m_A + m_B)} v_A = \frac{0.220\text{ kg}}{0.660\text{ kg}}(3.80\text{ m/s}) = 1.267\text{ m/s} \approx \boxed{1.27\text{ m/s (east)}}$$

$$v_B' = v_A + v_A' = 3.80\text{ m/s} + 1.27\text{ m/s} = \boxed{5.07\text{ m/s (east)}}$$

41. We apply the equation of continuity at constant density, Eq. 10–4b. The flow rate out of the duct must be equal to the flow rate into the room.

$$A_{\text{duct}}v_{\text{duct}} = \pi r^2 v_{\text{duct}} = \frac{V_{\text{room}}}{t_{\substack{\text{to fill}\\ \text{room}}}} \rightarrow v_{\text{duct}} = \frac{V_{\text{room}}}{\pi r^2 t_{\substack{\text{to fill}\\ \text{room}}}} = \frac{(8.2\text{ m})(5.0\text{ m})(3.5\text{ m})}{\pi(0.12\text{ m})^2(12\text{ min})\left(\frac{60\text{ s}}{1\text{ min}}\right)} = \boxed{4.4\text{ m/s}}$$

42. Use Eq. 10–4b, the equation of continuity for an incompressible fluid, to compare blood flow in the aorta and in the major arteries.

$$(Av)_{\text{aorta}} = (Av)_{\text{arteries}} \rightarrow$$

$$v_{\text{arteries}} = \frac{A_{\text{aorta}}}{A_{\text{arteries}}}v_{\text{aorta}} = \frac{\pi(1.2\text{ cm})^2}{2.0\text{ cm}^2}(40\text{ cm/s}) = 90.5\text{ cm/s} \approx \boxed{0.9\text{ m/s}}$$

43. We may apply Torricelli's theorem, Eq. 10–6.

$$v_1 = \sqrt{2g(y_2 - y_1)} = \sqrt{2(9.80\text{ m/s}^2)(4.7\text{ m})} = \boxed{9.6\text{ m/s}}$$

44. Bernoulli's equation is evaluated with $v_1 = v_2 = 0.$ Let point 1 be the initial point and point 2 be the final point.

$$P_1 + \tfrac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \tfrac{1}{2}\rho v_2^2 + \rho g y_2 \rightarrow P_1 + \rho g y_1 = P_2 + \rho g y_2 \rightarrow$$

$$P_2 - P_1 = \rho g(y_1 - y_2) \rightarrow \Delta P = -\rho g \Delta y$$

But a change in the y coordinate is the opposite of the change in depth, which is what is represented in Eq. 10–3b. So our final result is $\Delta P = \rho_0 g \Delta h,$ Eq. 10–3b.

45. The pressure head can be interpreted as an initial height for the water, with a speed of 0 and at atmospheric pressure. Apply Bernoulli's equation to the faucet location and the pressure head location to find the speed of the water at the faucet, and then calculate the volume flow rate. Since the faucet is open, the pressure there will be atmospheric as well.

$$P_{\text{faucet}} + \tfrac{1}{2}\rho v_{\text{faucet}}^2 + \rho g y_{\text{faucet}} = P_{\text{head}} + \tfrac{1}{2}\rho v_{\text{head}}^2 + \rho g y_{\text{head}} \rightarrow$$

$$v_{\text{faucet}}^2 = \frac{2}{\rho}(P_{\text{head}} - P_{\text{faucet}}) + v_{\text{head}}^2 + 2g(y_{\text{head}} - y_{\text{faucet}}) = 2gy_{\text{head}} \rightarrow$$

$$v_{\text{faucet}} = \sqrt{2gy_{\text{head}}}$$

$$\text{Volume flow rate} = Av = \pi r^2\sqrt{2gy_{\text{head}}} = \pi\left[\tfrac{1}{2}(1.85\times10^{-2}\text{ m})\right]^2\sqrt{2(9.80\text{ m/s}^2)(12.0\text{ m})}$$

$$= \boxed{4.12\times10^{-3}\text{ m}^3/\text{s}}$$

46. The flow speed is the speed of the water in the input tube. The entire volume of the water in the tank is to be processed in 4.0 h. The volume of water passing through the input tube per unit time is the volume rate of flow, as expressed in the text in the paragraph following Eq. 10–4b.

$$\frac{V}{\Delta t} = Av \rightarrow v = \frac{V}{A\Delta t} = \frac{\ell wh}{\pi r^2 \Delta t} = \frac{(0.36\text{ m})(1.0\text{ m})(0.60\text{ m})}{\pi(0.015\text{ m})^2(3.0\text{ h})\left(\frac{3600\text{ s}}{1\text{ h}}\right)} = 0.02829\text{ m/s} \approx \boxed{2.8\text{ cm/s}}$$

$\boxed{4.}$ (*a*) $2500\ \text{Cal}\left(\dfrac{4.186\times10^3\ \text{J}}{1\ \text{Cal}}\right)=\boxed{1.0\times10^7\ \text{J}}$

(*b*) $2500\ \text{Cal}\left(\dfrac{1\ \text{kWh}}{860\ \text{Cal}}\right)=\boxed{2.9\ \text{kWh}}$

(*c*) At 10 cents per day, the food energy costs $\boxed{\$0.29\ \text{per day}}$. It would be impossible to feed yourself in the United States on this amount of money.

5. On page 79 of the textbook, the conversion $1\ \text{lb}=4.44822\ \text{N}$ is given. We use that value.

$$1\,\text{Btu}=(1\ \text{lb})(1\ \text{F}^\circ)\left(\frac{4.44822\ \text{N}}{1\ \text{lb}}\right)\left(\frac{1\ \text{kg}}{9.80\text{m/s}^2}\right)\left(\frac{5/9\ \text{C}^\circ}{1\ \text{F}^\circ}\right)\frac{1\ \text{kcal}}{(1\ \text{kg})(1\ \text{C}^\circ)}=0.2522\ \text{kcal}\approx\boxed{0.252\ \text{kcal}}$$

$$0.2522\ \text{kcal}\left(\frac{4186\ \text{J}}{1\ \text{kcal}}\right)=\boxed{1056\ \text{J}}$$

6. The energy generated by using the brakes must equal the car's initial kinetic energy, since its final kinetic energy is 0.

$$Q=\tfrac{1}{2}mv_0^2=\tfrac{1}{2}(1300\ \text{kg})\left[(95\ \text{km/h})\left(\frac{1\ \text{m/s}}{3.6\ \text{km/h}}\right)\right]^2=4.526\times10^4\ \text{J}\approx\boxed{4.5\times10^4\ \text{J}}$$

$$4.526\times10^4\ \text{J}\left(\frac{1\ \text{kcal}}{4186\ \text{J}}\right)=108.1\ \text{kcal}\approx\boxed{110\ \text{kcal}}$$

7. The energy input is causing a certain rise in temperature, which can be expressed as a number of joules per hour per C°. Convert that to mass using the definition of kcal, relates mass to heat energy.

$$\left(\frac{3.2\times10^7\ \text{J/h}}{30\ \text{C}^\circ}\right)\left(\frac{1\ \text{kcal}}{4186\ \text{J}}\right)\frac{(1\ \text{kg})(1\ \text{C}^\circ)}{1\ \text{kcal}}=254.8\ \text{kg/h}\approx\boxed{250\ \text{kg/h}}$$

8. The wattage rating is 375 joules per second. Note that 1 L of water has a mass of 1 kg.

$$\left((2.5\times10^{-1}\ \text{L})\left(\frac{1\ \text{kg}}{1\ \text{L}}\right)(60\ \text{C}^\circ)\right)\frac{1\ \text{kcal}}{(1\ \text{kg})(1\ \text{C}^\circ)}\left(\frac{4186\ \text{J}}{\text{kcal}}\right)\left(\frac{1\ \text{s}}{375\ \text{J}}\right)=167\ \text{s}\approx\boxed{170\ \text{s}=2.8\ \text{min}}$$

9. The heat absorbed can be calculated from Eq. 14–2. Note that 1 L of water has a mass of 1 kg.

$$Q=mc\Delta T=\left[(18\ \text{L})\left(\frac{1\times10^{-3}\ \text{m}^3}{1\ \text{L}}\right)\left(\frac{1.0\times10^3\ \text{kg}}{1\ \text{m}^3}\right)\right](4186\ \text{J/kg}\cdot\text{C}^\circ)(95^\circ\text{C}-15^\circ\text{C})=\boxed{6.0\times10^6\ \text{J}}$$

10. The specific heat can be calculated from Eq. 14–2.

$$Q=mc\Delta T\ \ \rightarrow\ \ c=\frac{Q}{m\Delta T}=\frac{1.35\times10^5\ \text{J}}{(4.1\ \text{kg})(37.2^\circ\text{C}-18.0^\circ\text{C})}=1715\ \text{J/kg}\cdot\text{C}^\circ\approx\boxed{1700\ \text{J/kg}\cdot\text{C}^\circ}$$

$\boxed{9.}$ (*a*) Use Eq. 18–2 for resistance.

$$R = \frac{V}{I} = \frac{120\text{ V}}{13.5\text{ A}} = 8.889\ \Omega \approx \boxed{8.9\ \Omega}$$

(*b*) Use the definition of current, Eq. 18–1.

$$I = \frac{\Delta Q}{\Delta t} \quad \rightarrow \quad \Delta Q = I\Delta t = (13.5\text{ A})(15\text{ min})(60\text{ s/min}) = 1.215\times10^4\text{ C} \approx \boxed{1.2\times10^4\text{ C}}$$

10. Find the current from the voltage and resistance and then find the number of electrons from the current.

$$V = IR \quad \rightarrow \quad I = \frac{V}{R} = \frac{4.5\text{ V}}{1.3\ \Omega} = 3.462\text{ A}$$

$$3.462\text{ A} = 3.462\frac{\text{C}}{\text{s}} \times \frac{1\text{ electron}}{1.60\times10^{-19}\text{ C}} \times \frac{60\text{ s}}{1\text{ min}} = \boxed{1.3\times10^{21}\text{ electrons/min}}$$

11. (*a*) If the voltage drops by 15%, and the resistance stays the same, then by Eq. 18–2, $V = IR$, the current will also drop by 15%.

$$I_{\text{final}} = 0.85 I_{\text{initial}} = 0.85(5.60\text{ A}) = 4.76\text{ A} \approx \boxed{4.8\text{ A}}$$

(*b*) If the resistance drops by 15% (the same as being multiplied by 0.85), and the voltage stays the same, then by Eq. 18–2, the current must be divided by 0.85.

$$I_{\text{final}} = \frac{I_{\text{initial}}}{0.85} = \frac{5.60\text{ A}}{0.85} = 6.588\text{ A} \approx \boxed{6.6\text{ A}}$$

12. Use Eq. 18–3 to find the diameter, with the area $A = \pi r^2 = \pi d^2/4$.

$$R = \rho\frac{\ell}{A} = \rho\frac{4\ell}{\pi d^2} \quad \rightarrow \quad d = \sqrt{\frac{4\ell\rho}{\pi R}} = \sqrt{\frac{4(1.00\text{ m})(5.6\times10^{-8}\ \Omega\cdot\text{m})}{\pi(0.32\ \Omega)}} = \boxed{4.7\times10^{-4}\text{ m}}$$

13. Use Eq. 18–3 to calculate the resistance, with the area $A = \pi r^2 = \pi d^2/4$.

$$R = \rho\frac{\ell}{A} = \rho\frac{4\ell}{\pi d^2} = (1.68\times10^{-8}\ \Omega\cdot\text{m})\frac{4(5.4\text{ m})}{\pi(1.5\times10^{-3}\text{ m})^2} = \boxed{5.1\times10^{-2}\ \Omega}$$

14. Use Eq. 18–3 to calculate the resistances, with the area $A = \pi r^2 = \pi d^2/4$, so $R = \rho\frac{\ell}{A} = \rho\frac{4\ell}{\pi d^2}$.

$$\frac{R_{\text{Al}}}{R_{\text{Cu}}} = \frac{\rho_{\text{Al}}\frac{4\ell_{\text{Al}}}{\pi d_{\text{Al}}^2}}{\rho_{\text{Cu}}\frac{4\ell_{\text{Cu}}}{\pi d_{\text{Cu}}^2}} = \frac{\rho_{\text{Al}}\ell_{\text{Al}}d_{\text{Cu}}^2}{\rho_{\text{Cu}}\ell_{\text{Cu}}d_{\text{Al}}^2} = \frac{(2.65\times10^{-8}\ \Omega\cdot\text{m})(10.0\text{ m})(1.8\text{ mm})^2}{(1.68\times10^{-8}\ \Omega\cdot\text{m})(24.0\text{ m})(2.2\text{ mm})^2} = \boxed{0.44}$$

Differences: In double-slit interference the central maximum has the same angular width as each of the other maxima. In single-slit diffraction the central maximum is much wider than any of the other maxima. Double-slit interference has equations for the location of both the maxima and minima, and the maxima are located exactly between the minima. Single-slit diffraction only has a (simple) equation for the location of the minima. The maxima are not located exactly at the midpoint between each minimum.

3. Fig. 24–16: Inside the raindrop the violet light is refracted at a slightly greater angle than the red light, because each wavelength of light has a slightly different index of refraction in water. The two colors then reflect off the back of the raindrop at different positions and exit the front of the raindrop with the violet closer to the horizontal than the red, with the other colors between these two extremes. For an observer to see the violet light, the rain droplets must be lower in the sky than the droplets that refract the red light to the observer. The observer sees the red light from droplets higher in the sky and the violet light from lower droplets.

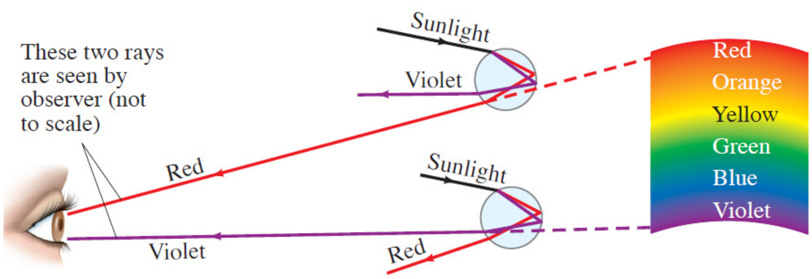
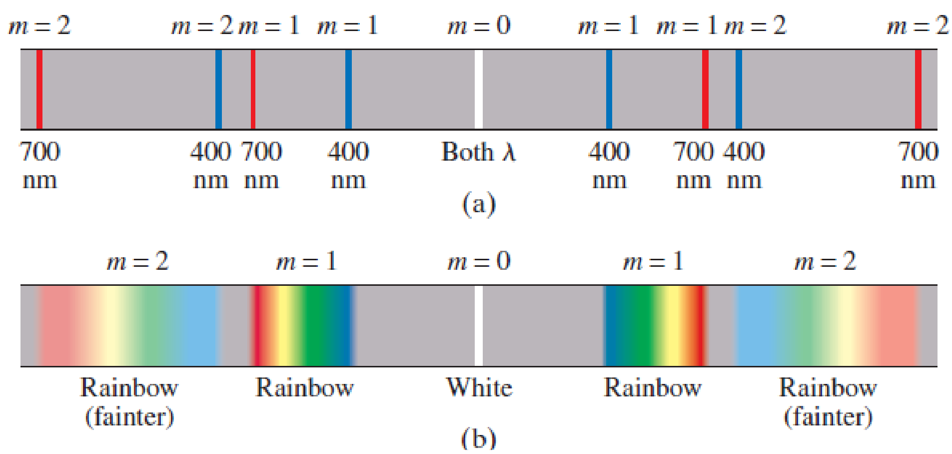


Fig. 24–26: In a diffraction grating the angle of diffraction is directly related to the wavelength. Since red light has a greater wavelength than violet light, it is diffracted more and appears farther from the central maximum than does the violet light.



4. Geometric optics is useful for studying reflection and refraction through lenses and mirrors whose physical dimensions are much larger than the wavelength of light. When dealing with objects (slits and thin films) whose dimensions are roughly the same order of magnitude as the wavelength of light we must use the more complicated wave nature of light. The physical characteristics that determines whether we must use the wave nature are the size of the object interacting with the light and the wavelength of the light.