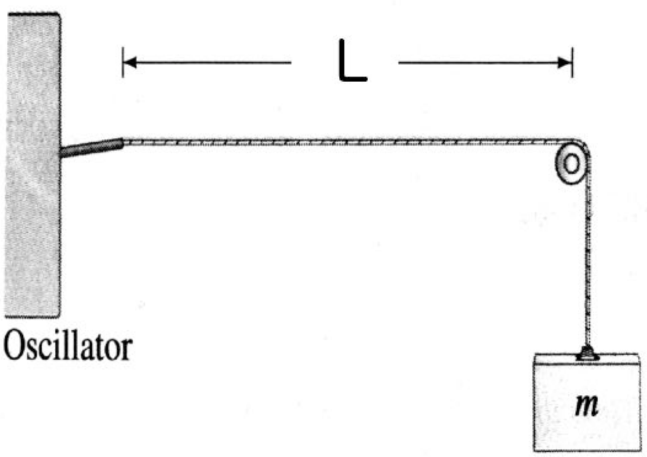
Physics 9, Fall 2018, Practice Exam. **Name:** BILL

This open-book take-home exam is 10% of your course grade. (The in-class final exam will be 25% of your course grade. For the in-class exam, you can bring one sheet of handwritten notes and a calculator. You will turn in your sheet of notes [if any] with your final exam.) You should **complete this exam on your own, without working with other people.** It is fine to discuss general topics from the course with your classmates, but it is not OK to share your solutions to these specific problems. Feel free to approximate $g = 10\ \mathrm{m/s^2}$ if you wish. The in-class exam will be shorter than this practice exam and will consist mainly of problems very similar to problems you have already solved in the weekly homework; the topics covered will be very similar to this practice exam.

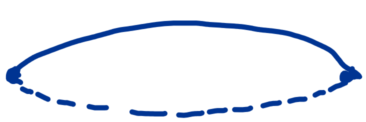
Due in class on Monday, December 10, 2018

Please show your work on these sheets. Use blank sheets at back if needed.

1. (7%) One end of a horizontal string is attached to a small-amplitude mechanical 75.0 Hz oscillator. The string's mass per unit length is $5.3 \times 10^{-4}\ \mathrm{kg/m}$. The string passes over a pulley, a distance $L = 1.75\ \mathrm{m}$ away, and weights are hung from this end. Assume the string at the oscillator is a node, which is nearly true, and that the string at the pulley is also a node.



(a) Sketch the shape of the string for the fundamental (lowest possible frequency) standing-wave mode of vibration of this string. In this case, how many wavelengths fit on the string?



$\frac{1}{2}\lambda = L$

One-half wavelength fits on string

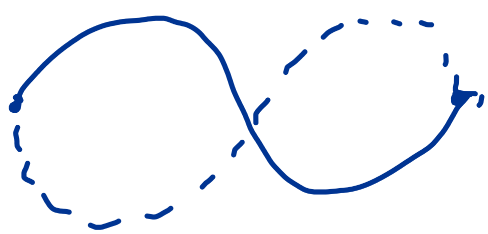
(Problem continues on next page.)

(b) What mass m must be hung from the right end of the string so that the string tension is what is needed to produce the standing wave that you drew in part (a) [at the given 75 Hz oscillation frequency]?

$m = 3.73$ kg

my calculations for all values are in the appended Mathematica notebook.

(c) Sketch the shape of the string for the second harmonic (next possible frequency above the fundamental) mode of vibration of this string. In this case, how many wavelengths fit on the string?



$\lambda = L$

one full wavelength fits on string.

(d) What mass m must be hung from the right end of the string to produce the standing wave that you drew in part (c)? (Tricky: The 75.0 Hz oscillator frequency is fixed, but you are changing the tension so that the mode that you drew in (c) has a frequency of 75.0 Hz.)

$m = 0.93$ kg

2. (7%) An unfingered guitar string is 0.63 m long and is tuned to play B (247 Hz) below middle C.

(a) How far from the far end of this string must your finger be placed (creating a node) to play E (330 Hz) above middle C? (In other words, what is the length of the portion of the string that you are allowing to vibrate at 330 Hz?)

My finger must be $\boxed{0.472\,\text{m}}$ from the far end of the string, which is 0.158 m from the near end.

(b) What is the wavelength on the string of this 330 Hz wave?

0.943 m

(c) What are the frequency and wavelength of the sound wave produced in room-temperature air ($v_{\text{sound}} = 343\,\text{m/s}$) by this fingered guitar string?

$f = 330\,\text{Hz}$

$\lambda = 1.04\,\text{m}$

3. (7%) At a rock concert, a dB meter (technically a "sound level meter") registered 110 dB when placed 3.5 m in front of a loudspeaker on stage.

(a) What was the power output of the speaker, assuming uniform spherical spreading of the sound and neglecting absorption in the air?

15.4 W

(b) How far away from the speaker would the sound level be 75 dB (assuming uniform spherical spreading of the sound waves, with no reflections, and neglecting absorption in the air)?

197 m

4. **(7%)** Busy street traffic has a typical intensity of $3.1 \times 10^{-5}\,\mathrm{W/m^2}$.

(a) What is the **intensity level** of this street noise, in dB? (As a reference level, the threshold of human hearing is $10^{-12}\,\mathrm{W/m^2}$.)

75 dB

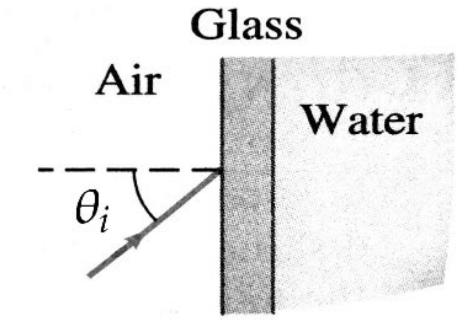
(b) Suppose that the window separating this busy street from your study has a **transmission loss** of 30 dB. With the window closed, and with no other noise source in your room, what is the intensity level (in dB) in your study?

45 dB

(c) What is the intensity (in $\mathrm{W/m^2}$) in your study due to the street noise (under the same conditions as part (b))?

$3.1 \times 10^{-8}\ \mathrm{W/m^2}$

5. (7%) An aquarium filled with water has flat glass sides whose index of refraction is 1.50. A beam of light from outside the aquarium strikes the glass at a $\theta_i = 35.0°$ angle to the perpendicular.



(a) What is the angle (w.r.t. perpendicular) of this light ray when it enters the glass?

22.48°

(b) What is the angle (w.r.t. perpendicular) of this light ray when it then enters the water (whose index of refraction is 1.33)?

25.55°

(c) What would be the refracted angle (w.r.t. perpendicular) if the ray entered the water directly (i.e. if the glass were absent)?

25.55°

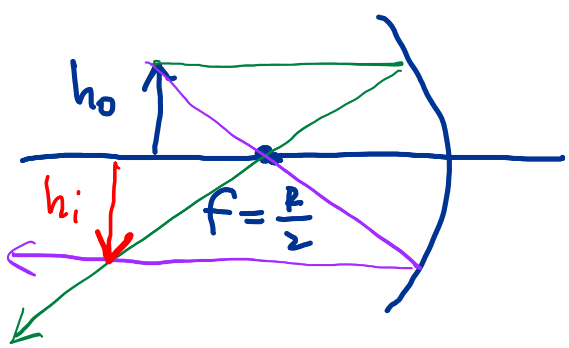
6. (8%) Use two techniques, (a) the mirror/lens equation, and (b) a ray diagram, to show that the image in a concave (converging) mirror [the type of mirror used for shaving or for applying makeup] is inverted (upside-down) if the object is beyond half of the radius of curvature ($d_o > R/2$), and is upright (not inverted) if the object is closer than half of the radius of curvature ($d_o < R/2$).

For converging mirror, $f = +\frac{R}{2}$

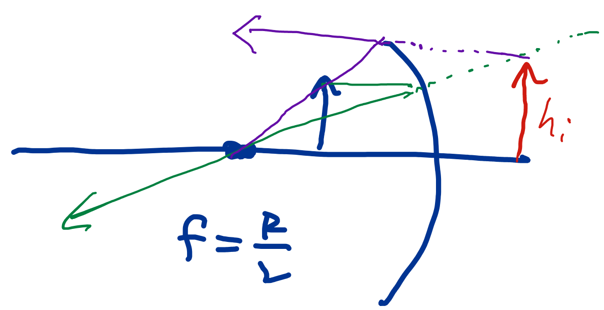
(a) Using $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$ & $\frac{h_i}{h_o} = -\frac{d_i}{d_o}$

$\Rightarrow h_i = \frac{h_o f}{f - d_o} = \frac{h_o R}{2(\frac{R}{2} - d_o)}$ numerator > 0 always.

If $d_o > \frac{R}{2}$ then $h_i < 0$ (denominator < 0).
If $d_o < \frac{R}{2}$ then $h_i > 0$ (denominator > 0).

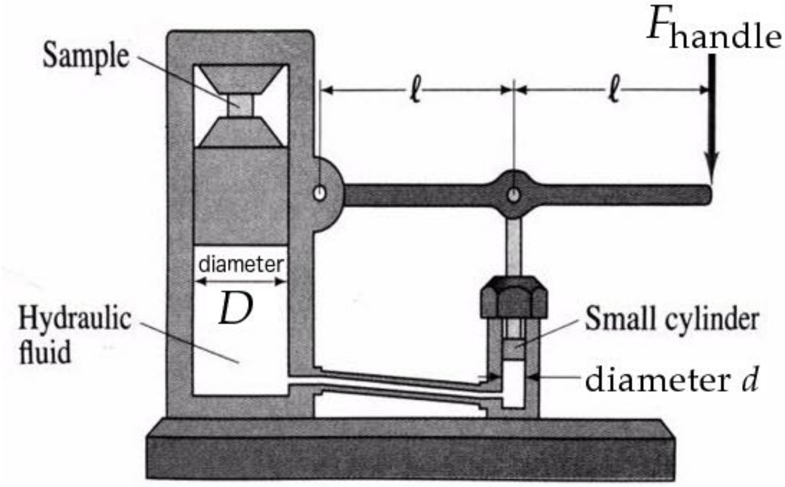


$d_o > \frac{R}{2}$ case: inverted



$d_o < \frac{R}{2}$ case: upright

7. (7%) A **hydraulic press** for compacting powdered samples[1] has a large cylinder which is $D = 12.0\,\text{cm}$ in **diameter**, and a small cylinder with a diameter of $d = 1.5\,\text{cm}$. A lever is attached to the small cylinder as shown. The sample, which is placed on the large cylinder, has an **area** of $3.0\,\text{cm}^2$. Your hand is applying a downward force $F_{\text{handle}} = 360\,\text{N}$ to the end of the lever.



(a) Find the **force** exerted by the large cylinder on the sample. [Hint, in case you were not in Physics 8: the $F_{\text{handle}} = 360\,\text{N}$ force at the end of the lever causes a $2F_{\text{handle}} = 720\,\text{N}$ downward force to be applied to the small cylinder, as a result of the torque and the 2:1 lever-arm ratio.]

$46.1\ \text{kN} = 46.1 \times 10^3\ \text{N}$

(b) Find the **pressure** exerted on the sample (initially, while the sample's area is still $3.0\,\text{cm}^2$, which probably is no longer true once the sample has been squished).

$1.54 \times 10^8\ \text{Pa} = 154\ \text{MPa}$

[1] Or for compacting folded paper! `https://youtu.be/KuG_CeEZV6w`

8. (7%) A crane lifts (slowly, and at constant velocity) the 23,000 kg steel (density $7800\,\mathrm{kg/m^3}$) hull of a sunken ship out of sea water (density $1025\,\mathrm{kg/m^3}$). Assume that the damaged hull is no longer water-tight — effectively it is just a steel brick. Determine the tension in the crane's cable

(a) when the hull is fully submerged in the water, and

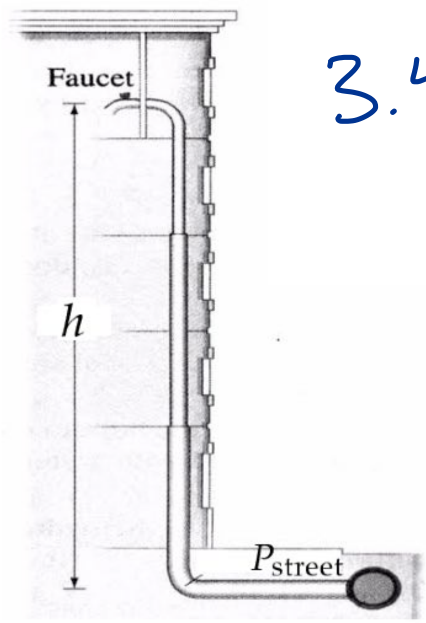
$196\ \mathrm{kN} = 196 \times 10^3\ \mathrm{N} = 1.96 \times 10^5\ \mathrm{N}$

(b) when the hull is completely out of the water.

$225\ \mathrm{kN} = 2.254 \times 10^5\ \mathrm{N}$

9. (7%) Water at a **gauge pressure** of $P_{\text{street}} = 4.7\,\text{atm}$ at street level flows into an office building at a speed of $0.62\,\text{m/s}$ through a pipe $6.0\,\text{cm}$ in **diameter**. The pipe tapers down to $2.54\,\text{cm}$ in diameter by the top floor, $h = 23\,\text{m}$ above, where the faucet has been left open.

(a) Using the continuity equation, calculate the flow velocity in the pipe on the top floor. (Assume steady flow and no pipe junctions.)



3.46 m/s

(b) Using Bernoulli's equation, calculate the **gauge pressure** in the pipe on the top floor. (This is within the pipe, before the faucet, so the water need not be at atmospheric pressure.)

245 kPa = 2.42 atm

10. (7%) (a) You buy an "airtight" bag of potato chips packaged at sea level, and take the chips on an airplane flight. When you take the potato chips out of the carry-on bag, you notice it has noticeably "puffed up." Airplane cabins are typically pressurized at 0.78 atm, and assuming the temperature inside an airplane is about the same as inside a potato chip factory, by what factor (in volume) has the bag "puffed up" in comparison to when it was packaged? To be specific, assume that the volume of the bag when sealed in the factory was 1.00 liter. What is its volume at cruising altitude inside the pressurized airplane cabin?

1.28 ℓ

using $P_1 V_1 = P_2 V_2$

(b) During the flight, you finish drinking a 1.00 liter bottle of water, and you screw the cap tightly onto the bottle at cruising altitude. During landing, the "empty" (except for air) bottle collapses to a smaller volume. Assuming that the bottle's wall is flexible so that the air pressure inside the bottle equals the air pressure outside the bottle, what is the volume of the crushed bottle once the plane lands?

0.78 ℓ

11. (7%) The pendulum in a grandfather clock is made of stainless steel ($\alpha = 12 \times 10^{-6}/°C$) and keeps perfect time at 20°C. How much time is gained or lost in a year if the clock is kept at 30°C? Assume the frequency dependence on length for a simple pendulum applies: $T = 2\pi\sqrt{L/g}$. (Be sure to convince me that you got the sign correct — be very explicit about what "gained or lost time" means to you.)

At the end of a year, the 30°C clock will be about $\boxed{\text{32 minutes slow,}}$ i.e. it will read 32 minutes earlier than true time.

$$1892\ s = 31.53 \text{ minutes}$$

using $L = L_0(1 + \alpha \Delta T)$

12. (7%) Two rooms, each a cube 4.5 m on a side, are separated by a concrete wall of thickness 11.0 cm. (The thermal conductivity of concrete is $k = 0.84\,\mathrm{J/(s \cdot m \cdot {}^\circ C)}$.) Because of a number of 100 W incandescent light bulbs in the first room, the air in the first room is at 25°C, while the air in the second room is somehow kept at 15°C (perhaps by a window open to 15°C outdoor air).

(a) How many 100 W incandescent light bulbs are needed in the first room to maintain the temperature difference across the wall? (Take the problem at face value and don't worry about what is happening at the other 5 walls of the first room — maybe the other 5 walls are very well insulated. Just calculate the heat per unit time conducted through the concrete wall due to the temperature difference between the two rooms, and assume that that heat must be supplied by the light bulbs.)

15.46 light bulbs → round up to 16

(b) What is the "R value" of this concrete wall? **Use SI metric units.** If you wanted to convert this into US customary units, you would use $1\,{}^\circ\mathrm{C \cdot m^2/W} \approx 5.7\,{}^\circ\mathrm{F \cdot ft^2 \cdot h/Btu}$. So in US customary units the R-value would be about 6× as large.

R value is $0.131 \dfrac{{}^\circ\mathrm{C}\,\mathrm{m}^2}{\mathrm{W}}$

(c) Go ahead and convert your R-value from part (b) into an R-value in US customary units.

R value is $0.75 \dfrac{{}^\circ\mathrm{F}\,\mathrm{ft}^2\,\mathrm{h}}{\mathrm{Btu}}$

That's "R − 0.75" which is quite poor.

13. (7%) A ground-source heat pump is used to supply 40°C hot water to an under-floor heating system that keeps your house warm in the winter.

(a) How much work (e.g. supplied by the electric mains) must be done on the heat pump to deliver 4000 J of heat into the house if the heat pump's COP is 4.0 (which is pretty realistic for a ground-source heat pump)?

1000 J

(b) Redo the above calculation using the COP of an ideal (Carnot) heat pump, assuming an underground ("cold") input temperature of 10°C and an indoor ("hot") output temperature of 40°C. (We have to make the "hot" temperature of the heat pump quite a bit hotter than the desired air temperature of your house. 40°C is a plausible number for an under-floor system.) Remember that the (ideal, best theoretically possible) Carnot heat pump has a COP equal to $T_H/(T_H - T_L)$, with temperatures measured in kelvin. You can see that a realistic heat pump is quite far from the Carnot ideal, but it is still worth bearing in mind that in general a heat pump's COP deteriorates when the temperature difference $T_H - T_L$ becomes too large.

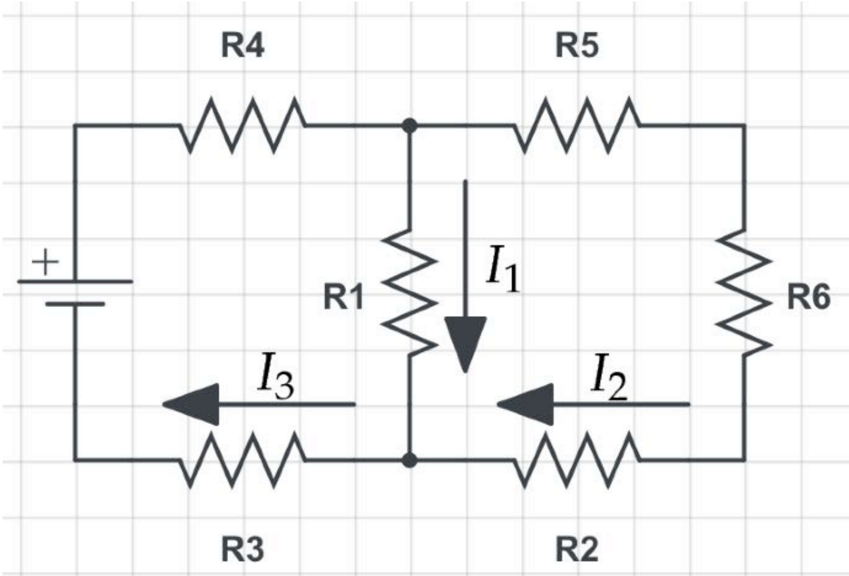
383 J $\quad (COP_{ideal} = 10.44)$

(c) In US customary units, one measures the removed heat in Btu = 1055 J but measures the electrical work in watt-hours = 3600 J. (Yuck!) So in the US, heat pumps, air conditioners, and refrigerators specify "SEER" instead of COP. A COP of 1.0 corresponds to a SEER of 3.4. What would be the corresponding SEER values for the COP values used in parts (a) and (b)?

SEER = 13.6

$SEER_{ideal} = 35.5$

14. (8%) For the circuit shown and labeled below:



(a) Use the "junction rule" to write a relationship between I_1, I_2, and I_3.

$$I_3 = I_1 + I_2$$

(b) Write down (but don't solve!) the three separate equations given by the "loop rule." One of these three equations will be redundant, in that it is just what you would get by adding or subtracting the two other equations from one another.

$$\mathcal{E} - I_3 R_4 - I_1 R_1 - I_3 R_3 = 0$$

$$\mathcal{E} - I_3 R_4 - I_2 R_5 - I_2 R_6 - I_2 R_2 - I_3 R_3 = 0$$

$$I_1 R_1 - I_2 R_5 - I_2 R_6 - I_2 R_2 = 0$$

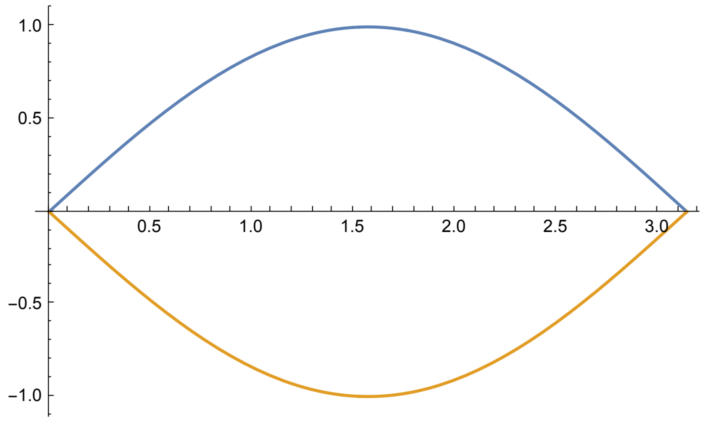
3rd eqn is just ② − ①

In[12]:=
```
Off[Reduce::ratnz];
```

Problem 1

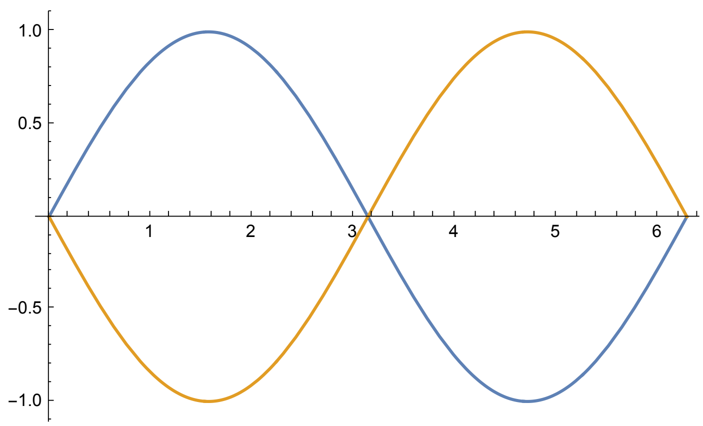
(a) **One-half wavelength** fits on the string in the fundamental mode.

In[5]:=
```
Plot[{Sin[x], -Sin[x]}, {x, 0, Pi}]
```

Out[5]=


(b) The necessary mass is m = **3.73 kilograms**.
(c) For the second harmonic, **one full wavelength** fits on the string.

In[25]:=
```
Plot[{Sin[x], -Sin[x]}, {x, 0, 2 Pi}]
```

Out[25]=


(d) To get double the wavelength at the same frequency, we reduce the wave speed by a factor of 2, which implies reducing the tension by a factor of 4, so the new block to suspend from the string must have mass m=**0.93 kilogram**.

In[161]:=
```
ClearAll["Global`*"];
meter = Quantity["meter"];
second = Quantity["second"];
newton = Quantity["newton"];
kilogram = Quantity["kilogram"];
soln = ToRules[Reduce[{
    v_wave == Sqrt[tension / mass_per_unit_length],
    length == 1.75 meter,
```

```
    mass_per_unit_length == mass / length,
    λ0 == 2 length,
    v_wave == λ0 f0,
    mass / length == 5.3 × 10^-4 kilogram / meter,
    f0 == 75.0 / second,
    g == 9.8 newton / kilogram,
    m g == tension
   }]]
```

Out[166]= {λ0 → 3.5 m , v_wave → 262.5 m/s , tension → 36.5203 N ,
mass_per_unit_length → 0.00053 kg/m , mass → 0.0009275 kg ,
m → 3.72656 kg , length → 1.75 m , g → 9.8 m/s^2 , f0 → 75. per second}

```
In[167]:= (m / 4 ) /. soln
```

Out[167]= 0.931641 kg

Problem 2

(a) The wave speed doesn’t change, but the length of the string changes, and the fundamental mode has a wavelength equal to twice the length (or effective length) of the string. My finger must be placed **0.472 meter** from the far end of the string (so my finger is 0.158 meter from the near end).
(b) At 330 Hz, the wavelength on the string is **0.943 meter**.
(c) The frequency in air is the same as the frequency on the guitar string: **330 Hz**. The wavelength in air is **1.04 meters**, given by v(sound) = lambda*f.

```
In[38]:= ClearAll["Global`*"];
meter = Quantity["meter"];
second = Quantity["second"];
hertz = 1 / second;
soln = ToRules[Reduce[{
    vwave == λ0 f0,
    vwave == λ1 f1,
    λ0 == 2 L0,
    λ1 == 2 L1,
    L0 == 0.63 meter,
    f0 == 247 hertz,
    f1 == 330 hertz,
    ΔL == L0 - L1
   }]]
```

Out[42]= {λ1 → 0.943091 m , λ0 → 1.26 m , ΔL → 0.158455 m , vwave → 311.22 m/s ,
L1 → 0.471545 m , L0 → 0.63 m , f1 → 330. per second , f0 → 247. per second}

```
In[37]:= soln1 = ToRules[Reduce[{
    vsound == 343.0 meter / second,
```

```
    vsound == λ f,
    f == 330 hertz
   }]]
```

Out[37]= {λ → 1.03939 m , vsound → 343. m/s , f → 330. per second}

Problem 3

(a) Total power emitted by loudspeaker is **15.4 watts**.
(b) For 75dB sound level, sit a distance **197 meters** from the loudspeaker.

In[168]:=
```
ClearAll["Global`*"];
meter = Quantity["meter"];
watt = Quantity["watt"];
soln = ToRules[Reduce[{
    decibelsNear == 110.0,
    referenceIntensity == 10^-12 watt / meter^2,
    intensityNear == referenceIntensity × 10^(0.1×decibelsNear),
    intensityNear == speakerPower / (4 π radiusNear^2),
    radiusNear == 3.5 meter,
    decibelsFar == 75.0,
    intensityFar == referenceIntensity × 10^(0.1×decibelsFar),
    intensityFar == speakerPower / (4 π radiusFar^2),
    radiusFar > 0
   }]]
```

Out[171]= {radiusFar → 196.819 m , speakerPower → 15.3938 W ,
referenceIntensity → $1.\times 10^{-12}$ kg/s³ , radiusNear → 3.5 m , intensityNear → 0.1 kg/s³ ,
intensityFar → 0.0000316228 kg/s³ , decibelsNear → 110., decibelsFar → 75.}

Problem 4

(a) The intensity level of the street noise is **75dB**.
(b) With the 30dB window closed, the intensity level indoors is **45dB**.
(c) The intensity indoors is $\mathbf{3.1\times 10^{-8}}$ **W/*m*^{2}**

In[172]:=
```
ClearAll["Global`*"];
watt = Quantity["watt"];
meter = Quantity["meter"];
soln = ToRules[Reduce[{
    referenceIntensity == 10^-12 watt / meter^2,
    intensityOutside == 3.1 × 10^-5 watt / meter^2,
    decibelsOutside == 10 Log10[intensityOutside / referenceIntensity],
    decibelsTL == 30.0,
```

```
    decibelsInside == decibelsOutside - decibelsTL,
    intensityInside == referenceIntensity × 10^(0.1×decibelsInside)
   }]]
```

Out[175]= {referenceIntensity → 1. × 10^-12 kg/s^3 , intensityOutside → 0.000031 kg/s^3 , intensityInside → 3.1 × 10^-8 kg/s^3 , decibelsTL → 30., decibelsOutside → 74.9136, decibelsInside → 44.9136}

Problem 5

(a) The transmitted angle into the glass is 22.48 degrees.
(b) The transmitted angle into the water is 25.55 degrees.
(c) The transmitted angle into the water is still 25.55 degrees.

In[89]:=
```
ClearAll["Global`*"];
soln = ToRules[Reduce[{
    nair Sin[θair Degree] == nglass Sin[θglass Degree],
    nair == 1.0,
    nglass == 1.50,
    θair == 35.0,
    nglass Sin[θglass Degree] == nwater Sin[θwater Degree],
    nwater == 1.33,
    0 < θglass < 90,
    0 < θwater < 90
   }, {θglass}]]
```

Out[90]= {nair → 1., nglass → 1.5, nwater → 1.33, θair → 35., θwater → 25.5476, θglass → 22.4814}

Problem 6

(a) The focal length for a converging mirror is f = +R/2. Plugging into the lens/mirror equation, the image height is hi = (ho R/2) / (R/2 - do). The numerator is always positive. If do > R/2 then the denominator is negative, and the image height is negative: inverted. If do < R/2 then the denominator is positive, and the image height is positive: upright.
(b) Draw diagram on exam PDF.

In[113]:=
```
ClearAll["Global`*"];
soln = Reduce[{
   1 / f == 1 / do + 1 / di,
   hi / ho == -di / do,
   f == +r / 2,
   r > 0, do > 0, ho > 0
  }]
```

Out[114]= $r > 0 \,\&\&\, \left(\left(0 < do < \frac{r}{2} \,\&\&\, ho > 0\right) \,||\, \left(do > \frac{r}{2} \,\&\&\, ho > 0\right)\right) \,\&\&\, hi == -\frac{ho\, r}{2\left(do - \frac{r}{2}\right)} \,\&\&\, f == \frac{r}{2} \,\&\&\, di == \frac{do\, f}{do - f}$

Problem 7

(a) The force exerted by the large cylinder on the sample is **46.1 kN**, or **46.1×10^3 N**.
(b) The pressure exerted by the large cylinder on the sample is **1.54×10^8 Pa**, or **154 MPa**.

In[140]:=
```
ClearAll["Global`*"];
meter = Quantity["meter"];
cm = 0.01 meter;
newton = Quantity["newton"];
soln = ToRules[Reduce[{
    pressure == forceWide / areaWide,
    pressure == forceNarrow / areaNarrow,
    dNarrow == 1.5 cm,
    dWide == 12.0 cm,
    areaNarrow == Pi (dNarrow / 2)^2,
    areaWide == Pi (dWide / 2)^2,
    fHandle == 360.0 newton,
    forceNarrow == 2 fHandle,
    pressureSample == forceWide / areaSample,
    areaSample == 3.0 cm^2
   }]]
```

Out[144]= {pressureSample → 1.536×10^8 Pa, pressure → 4.07437×10^6 Pa, forceWide → 46 080. N, forceNarrow → 720. N, fHandle → 360. N, dWide → 0.12 m, dNarrow → 0.015 m, areaWide → 0.0113097 m^2, areaSample → 0.0003 m^2, areaNarrow → 0.000176715 m^2}

Problem 8

(a) When the hull is fully submerged, the tension in the cable is **196kN** = 196×10^3N = 1.96×10^5N.
(b) When the hull is completely out of the water, the tension in the cable is **225kN** = 2.254×10^5N.

In[150]:=
```
ClearAll["Global`*"];
kilogram = Quantity[1.0, "kilogram"];
```

```
newton = Quantity[1.0, "newton"];
meter = Quantity[1.0, "meter"];
soln = ToRules[Reduce[{
    hullMass == 23 000 kilogram,
    steelDensity == 7800 kilogram / meter^3,
    seaWaterDensity == 1025 kilogram / meter^3,
    g == 9.8 newton / kilogram,
    buoyantForce == g × hullVolume × seaWaterDensity,
    hullMass == hullVolume × steelDensity,
    submergedTension + buoyantForce == hullMass × g,
    nonSubmergedTension == hullMass × g
   }]]
```

```
Out[154]= {submergedTension → 195 780. kg m/s^2 ,
 steelDensity → 7800. kg/m^3 , seaWaterDensity → 1025. kg/m^3 ,
 nonSubmergedTension → 225 400. kg m/s^2 , hullVolume → 2.94872 m^3 ,
 hullMass → 23 000. kg , g → 9.8 m/s^2 , buoyantForce → 29 619.9 kg m/s^2 }
```

Problem 9

(a) Using continuity equation, flow speed at top floor is **3.46 m/s**.
(b) Gauge pressure at top floor is **245kPa = 2.42atm**.

```
In[199]:= ClearAll["Global`*"];
pascal = Quantity[1.0, "pascal"];
atm = 101 325 pascal;
meter = Quantity[1.0, "meter"];
second = Quantity[1.0, "second"];
kilogram = Quantity[1.0, "kilogram"];
cm = 0.01 meter;
soln = ToRules[Reduce[{
    pstreet == 4.7 atm,
    vstreet == 0.62 meter / second,
    dstreet == 6.0 cm,
    astreet == π (dstreet / 2)^2,
    dtop == 2.54 cm,
    atop == π (dtop / 2)^2,
    vtop × atop == vstreet × astreet,
    ptop + (1 / 2) ρwater vtop^2 + ρwater g htop ==
     pstreet + (1 / 2) ρwater vstreet ^ 2 + ρwater g hstreet,
    g == 9.8 meter / second^2,
    hstreet == 0,
```

```
    htop == 23 meter,
    ρwater == 1000 kilogram / meter^3,
    atmtop == ptop / atm
   }]]
```

Out[206]= {ρwater → 1000. kg/m^3 , vtop → 3.45961 m/s , vstreet → 0.62 m/s , ptop → 245 035. Pa ,
pstreet → 476 228. Pa , htop → 23. m , hstreet → 0 m , g → 9.8 m/s^2 , dtop → 0.0254 m ,
dstreet → 0.06 m , atop → 0.000506707 m^2 , astreet → 0.00282743 m^2 , atmtop → 2.41831}

Problem 10

(a) Bag volume at cruising altitude will be **1.28 liter**.
(b) Volume of empty water bottle on landing will be **0.78 liter**.

In[244]:=
```
ClearAll["Global`*"];
atm = Quantity[101 325.0, "pascal"];
liter = Quantity[1.0, "liter"];
soln = ToRules[Reduce[{
    pground == 1.0 atm,
    pcabin == 0.78 atm,
    vground == 1.00 liter,
    pground × vground == pcabin × vcabin
   }]]
UnitConvert[vcabin, "liter"] /. soln
```

Out[247]= {vground → 0.001 m^3 , vcabin → 0.00128205 m^3 ,
pground → 101 325. kg/(m s^2) , pcabin → 79 033.5 kg/(m s^2) }

Out[248]= 1.28205 L

In[249]:=
```
soln = ToRules[Reduce[{
    pground == 1.0 atm,
    pcabin == 0.78 atm,
    vcabin == 1.00 liter,
    pground × vground == pcabin × vcabin
   }]]
UnitConvert[vground, "liter"] /. soln
```

Out[249]= {vground → 0.00078 m^3 , vcabin → 0.001 m^3 ,
pground → 101 325. kg/(m s^2) , pcabin → 79 033.5 kg/(m s^2) }

Out[250]= 0.78 L

Problem 11

At the end of a year, the clock will be about **32 minutes slow**, i.e. it will read a time that is 32 minutes earlier than a clock that keeps perfect time.

In[279]:=
```
ClearAll["Global`*"];
celsius = Quantity[1.0, "celsius"];
meter = Quantity[1.0, "meter"];
second = Quantity[1.0, "second"];
soln = ToRules[Reduce[{
    period20 == 2 π Sqrt[L20 / g],
    period30 == 2 π Sqrt[L30 / g],
    α == 12 × 10^-6 / celsius,
    T30 == 30 celsius,
    T20 == 20 celsius,
    ΔT == T30 - T20,
    L30 == L20 (1 + α ΔT),
    secondsLost == 365 × 24 × 3600 × (period30 / period20 - 1),
    minutesLost == secondsLost / 60,
    g == 9.8 meter / second^2,
    L20 == 1.0 meter
   }]]
```

Out[283]=
```
{ΔT → 10. K, α → 0.000012/K, T30 → 30. K, T20 → 20. K,
 period30 → 2.00721 s, period20 → 2.00709 s, L30 → 1.00012 m,
 L20 → 1. m, g → 9.8 m/s^2, secondsLost → 1892.1, minutesLost → 31.5351}
```

Problem 12

(a) We need **15.46** light bulbs, so round up to 16.
(b) R value is 0.131 °C × m^2/ W.
(c) In US customary units, R value is 0.75 °F × ft^2×h/Btu. That's a pretty poor R-value, i.e. it is smaller than "R-1."

In[309]:=
```
ClearAll["Global`*"];
second = Quantity[1.0, "second"];
meter = Quantity[1.0, "meter"];
cm = 0.01 meter;
celsius = Quantity[1.0, "celsius"];
watt = Quantity[1.0, "watt"];
soln = ToRules[Reduce[{
    thermalPower == area × ΔT / rvalue,
    area == (4.5 meter)^2,
```

```
    thickness == 11 cm,
    rvalue == thickness / thermalConductivity,
    thermalConductivity == 0.84 watt / (meter × celsius),
    Tindoor == 25 celsius,
    Toutdoor == 15 celsius,
    ΔT == Tindoor - Toutdoor,
    nLightBulbs == thermalPower / (100 watt)
   }]]
```

Out[315]=
```
{ΔT → 10. K , Toutdoor → 15. K , Tindoor → 25. K , thickness → 0.11 m ,
 thermalPower → 1546.36 W , thermalConductivity → 0.84 kg m/(s^3 K) ,
 rvalue → 0.130952 s^3 K/kg , area → 20.25 m^2 , nLightBulbs → 15.4636}
```

In[316]:=
```
0.130952 × 5.7
```

Out[316]=
```
0.746426
```

Problem 13

(a) Work required = **1000 J**.
(b) Now work required = **383 J**.
(c) SEER (realistic) = **13.6**, SEER (ideal) = **35.5**.

In[350]:=
```
ClearAll["Global`*"];
joule = Quantity[1.0, "joule"];
kelvin = Quantity[1.0, "kelvin"];
soln = ToRules[Reduce[{
    COP == 4.0,
    Q == 4000 joule,
    W == Q / COP,
    Thot == (40 + 273.15) kelvin,
    Tcold == (10 + 273.15) kelvin,
    COPideal == Thot / (Thot - Tcold),
    Wideal == Q / COPideal,
    SEER == 3.4 COP,
    SEERideal == 3.4 COPideal
   }]]
```

Out[353]=
```
{Wideal → 383.203 J , W → 1000. J , Thot → 313.15 K , Tcold → 283.15 K ,
 Q → 4000. J , SEERideal → 35.4903, SEER → 13.6, COPideal → 10.4383, COP → 4.}
```

Problem 14

(a)

$I_3 = I_1 + I_2$.

(b)

$\mathcal{E}$ - $I_3\, R_4 - I_1\, R_1 - I_3\, R_3 = 0$
$\mathcal{E}$ - $I_3\, R_4 - I_2\, R_5 - I_2\, R_6 - I_2\, R_2 - I_3\, R_3 = 0$
$I_1\, R_1 - I_2\, R_5 - I_2\, R_6 - I_2\, R_2 = 0$