PS3

September 26, 2023

1 Problem Set 3

The first cell (below) contains lots of helpful constants you may need to use throughout the semester. Make sure to run it each time before you start working!

For reference, all of the `astropy` constants as well as examples can be found here. Likewise all of the units and their names / how to access them can be found here.

To create a variable with units you need to multiply by the corresponding unit class:

`d = 1 * units.au`

You can then convert unitful quantities to other units by calling the `to` method and passing the desired end unit class:

`d_m = d.to(units.m)`

If you have a ratio of quanities where all the units should cancel out, you can obtain the dimensionles number using the `dimesionless_unscaled` method. For example writing:

`d_m/d`

yields $1.4959787 \times 10^{11} \frac{\mathrm{m}}{\mathrm{AU}}$, but doing:

`(d_m/d).to(units.dimensionless_unscaled)`

returns `1.0` as expected.

Sometimes you may get answers in weird units, but many of them can cancel out. A handy trick for seeing which units cancel is to write `.si` after the quantity, i.e. `d.si` and it will conver whatever units you have to SI units.

1.0.1 Make sure to run the cell below before starting your homework!!!

[ ]:
```python
#SETUP CELL (modify at your own peril)
from astropy import units #access units by doing units.<unit> (i.e. units.au)
from astropy import constants
import numpy as np #common math functions (i.e. np.sin(x)) and better arrays (i.
↪e. np.array([1,2,3])
import matplotlib.pyplot as plt #plotting functions (i.e. plt.plot(x,y))
G = constants.G # gravitational constant
M_sun = constants.M_sun # mass of the sun
R_sun = constants.R_sun # radius of the sun
```

```
L_sun = constants.L_sun # luminosity of the sun
M_earth = constants.M_earth # mass of the earth
R_earth = constants.R_earth # radius of the earth
M_jup = constants.M_jup # mass of jupiter
R_jup = constants.R_jup # radius of jupiter
sigma_sb = constants.sigma_sb # Stefan-Boltzmann constant
c = constants.c # speed of light
h = constants.h # Planck constant
k_B = constants.k_B # Boltzmann constant
m_e = constants.m_e # mass of electron
m_p = constants.m_p # mass of proton
m_n = constants.m_n # mass of neutron (basically just the mass of a proton but
 ↪whatever)
g0 = constants.g0 # standard gravity, 9.8 m/s^2
e = constants.e # absolute value of electron/proton charge
```

1.1 Q1 (40 pts)

1.1.1 Gravitational heating

This problem presents one of several early mathematical tests of the nebular theory. A star needs to get its core temperature to roughly 15 million K to sustain fusion reactions. For stars to be formed from large clouds of cool gas something must heat them up as they contract — your job in this problem will be to test if there is enough gravitational energy available to cause a newly formed star to heat up sufficiently to start nuclear fusion. The goal is not to be exact but just to check if it is plausible that stars form from interstellar clouds, thus all answers only need $\sim$ 1-2 significant figures (the order of magnitude is really what we're after here).

1.1.2 a.)

Consider 1 kg of hydrogen falling onto the Sun during its late-stage formation. If the hydrogen free-falls from greater than 1 ly away, how much gravitational energy is converted to kinetic energy by the time this 1 kg of H reaches just above the Sun's surface? Assume that the Sun is nearly completely formed (so that its mass and radius are the same as they are today). Calculate and report your answer in the code cell below.

[ ]:
```
m = 1 * units.kg
d = 1 * units.lyr
E_g = (m * g0 * d).to(units.J)
# E_g = E_k ==> (m * g * h) = (0.5 * m * v**2)
E_g
```

[ ]: 9.2778072×10^{16} J

1.1.3 b.)

Hydrogen is made up of just a single proton and electron, and since electrons have very little mass compared to protons the mass of each hydrogen atom is basically just the mass of a proton. Using this fact, how many hydrogen atoms are there inside the 1 kg parcel we just dropped onto the Sun? Calculate and report your answer in the code cell below.

[ ]:
```
# m_n * x = m
x = m / m_n
x
```

[ ]: 5.9704077×10^{26}

1.1.4 c.)

Upon impact, the kinetic energy is converted into thermal energy. Using your answer from parts a.) and b.), calculate how much thermal energy (on average) each hydrogen atom has after the impact. Use the code cell below to calculate and report your answer.

[ ]:
```
# E_t = kinetic E of particles
# E_g / x = kinetic E of one particle
E_a = (E_g / x).to(units.J)
E_a
```

[ ]: $1.5539654 \times 10^{-10}$ J

1.1.5 d.)

Temperature is simply a measure of the average energy per atom, often expressed as $E = \frac{3}{2}k_BT$. Thus we can use Boltzmann's constant (k_B) to convert from average energy per atom to temperature. How hot is the Hydrogen? Calculate and report your answer in the code cell below.

[ ]:
```
# T = E / (3/2 * k_B)
T_a = (E_a / (1.5 * k_B)).si
T_a
```

[ ]: 7.5035506×10^{12} K

1.1.6 e.)

Based on your answers above, do you think there is enough gravitational energy in a collapsing cloud to start nuclear fusion? Provide your answer in the markdown cell below.

As stated, the minimum temperature a star must reach to sustain nuclear fusion is 15×10^6K. In part (d) I found that the Hydrogen's temperature is equal to ~7.5×10^{12}K. Since this is 6 orders of magnitude greater than the minimum temperature there is enough gravitational energy to start nuclear fusion.

1.2 Q2 (30 pts)

1.2.1 Standing on a white dwarf

1.2.2 a.)

Calculate the gravitational ***acceleration*** objects feel on Earth's surface. Hint: you will need Earth's mass and radius. Calculate and provide your answer (in m/s^2) in the code cell below.

[ ]:
```
# F_grav = m * g
# a_g = F_grav / m
# a_g = (G*M_earth*M / R**2)
# / M => G*M_earth / R**2
a_gE = ((G * M_earth) / (R_earth**2)).si
a_gE
```

[ ]: $9.7983981 \ \frac{\mathrm{m}}{\mathrm{s}^2}$

1.2.3 b.)

The answer above is known as 1 g, and should be roughly 9.8 m/s^2. Calculate the gravitational acceleration on the Sun at its photosphere (from the core to the photosphere is usually how we define $R_\odot$). How many g's would you feel if you could stand on the surface of the Sun? The Sun is 300,000 times more massive than the Earth, so why is the Sun's surface gravity so low? Calculate and provide your answers in the code and/or markdown cells below.

[ ]:
```
# surface gravity is proportional to m / r^2

a_gS = ((G * M_sun) / (R_sun**2)).si
n_S = a_gS / a_gE
print(f"You would feel {n_S} g's on the Sun's surface.")
```

```
You would feel 27.984177404994483 g's on the Sun's surface.
```

Even though the Sun is 300,000 times more massive than Earth, we can see that $a_g \propto \frac{M}{R^2}$, indicating that radius (or distance) is more impactful on an object's surface gravity than its mass, since R is squared.

1.2.4 c.)

In about 5 billion years, the Sun will burn out and collapse into a white dwarf. Its mass will be roughly the same but its radius will be nearly the same as the Earth's. What will the gravitational acceleration be on the (now white dwarf) Sun then? How many g's would you feel on a white dwarf? Calculate and provide your answer in the code cell below.

[ ]:
```
a_gWD = ((G * M_sun) / (R_earth**2)).si
n_WD = a_gWD / a_gE
print(f"The gravitational acceleration on the white dwarf version of the Sun␣
 ↪would be {a_gWD}, which is {n_WD} g's.")
```

```
The gravitational acceleration on the white dwarf version of the Sun would be
3262338.232502328 m / s2, which is 332946.07832806994 g's.
```

1.3 Q3 (30 pts)

1.3.1 The untapped genius that could change science for the better

Watch the following TED talk by Dartmouth Professor Jedidah Isler PhD. Jedidah was one of my closest friends in graduate school at Yale. When we would be working on homework together or having dinner together, I remember a number of conversations with her where she described something someone did and how it made her feel like she didn't belong. I have to admit, as embarrassing as it is, much of the time they were not things I'd ever thought of. Sometimes they were things I had done. Every time I would realize that, it was like a kick in the gut. My hope in having you engage with Jedidah's wisdom is that there are less interactions in this class that make people feel like they got kicked in the gut or that they don't belong. I believe strongly in all of your potential as scientists and it is important to me that I do what I can to make the astrophysical community one where you can contribute all your amazing insights to our understanding of the universe.

https://www.ted.com/talks/jedidah_isler_the_untapped_genius_that_could_change_science_for_the_better

1.3.2 a.)

Your friend who is not an astrophysics major asks what the video is about. Summarize it for them in five sentences or less in language that they will understand. Use the markdown cell below to provide your answer.

This TED talk by Jedidah Isler, PhD., is about the importance of honoring and prioritizing intersectionality in STEM fields. She speaks on her experience as a Black woman, and her disadvantaged position on her journey towards getting her PhD. Many of the obstacles she and others like her face relate back to their position in the world; they live at the intersection of race and gender, and while this introduces many biases and prejudices, it also gives them a unique opportunity and perspective in life, and in their work. So, she encourages all women and girls of color to follow their aspirations, regardless of the challenges that their race or gender may elicit, and suggests that these kinds of intersectional identities are invaluable in solving the countless intersectional problems we face as a society today.

1.3.3 b.)

In three sentences, tell the same friend the most interesting and/or important thing you learned / were reminded of. Use the markdown cell below to provide your answer.

One of the most interesting parts of this was when Dr. Isler quotes both Dr. Claudia Alexander and Jessica Matthews towards the end of the talk. I thought that she tied together the speech really nicely in noting how Dr. Alexander "shows exactly the power of a liminal person," and in Matthews' quote: " 'A major part of invention isn't just creating things, it's understanding people and understanding the systems that make this world' " (10:36, 10:54). Intersectionality in our work and personal relationships with people is crucial to progressing our understanding of the world, and in the creation of new systems and technologies that can help solve these complex problems.

1.3.4 c.)

Write a paragraph ($\sim$ 6 sentences) on a few thoughts/ideas you have that you would implement into a class you were teaching to make sure everyone feels encouraged and included. This is open-ended and can be related to the video and/or your experiences in college so far! What have you seen professors do that you really liked and/or disliked? Provide your answer in the markdown cell below.

If I was teaching a class, I would definitely start by making it a priority to do things like this! Listening to and reading stories from people in astrophysics who come from marginalized backgrounds is one great way I think to incorporate inclusivity and intersectionality into a class. I think for students who come from similar backgrounds find these assignments / activities encouraging, and it makes the classroom feel more inclusive as a whole. I think giving students a space to anonymously voice their opinions / concerns / thoughts / suggestions is also a good way to ensure students feel like their needs can be met. You could do this by sending out periodic feedback forms, clicker questions, or having a space within assignments where students can jot down these ideas. Professor Berta-Thompson did this really well last semester for ASTR 1030 and I really appreciated how much he valued the feedback from students.