

OpenStax Astronomy, Ch.20: WS Solutions (Apr-2021)

Solutions

1. Why do nebulae near hot stars look red? Why do dust clouds near stars usually look blue?

The red color of nebulae comes from the Balmer line produced when ionized hydrogen captures an electron and becomes neutral again. Nebulae are filled with ionized hydrogen that combine with an electron to produce this line. Dust clouds are blue because the light we see from them is scattered starlight. Blue light scatters more than red light, so the light we see coming off the clouds is bluer than the light from the stars.

2. Describe how the 21-cm line of hydrogen is formed. Why is this line such an important tool for understanding the interstellar medium?

The 21-cm line is formed when hydrogen atoms in which the proton and electron are aligned “flip” so that the proton and electron are anti-aligned. Hydrogen atoms that are in the anti-aligned state will be excited into the aligned state by collisions, and will subsequently emit a photon with a wavelength of 21 cm, giving rise to the line. The line is important because it is produced by neutral hydrogen everywhere. Since cold hydrogen atoms make up the largest part of the interstellar medium, the 21-cm line allows us to study the most common component of interstellar gas.

3. Describe the properties of the dust grains found in the space between stars.

Interstellar dust grains are typically hundredths to tenths of a micron size. They are composed of either carbon-rich (sooty) or silicate (sandy) material. When found inside dark clouds, they also have mantles of ice, composed of water, ammonia, methane, and similar materials around them. Dust grains can have temperatures from around 10–500 K.

4. Why is it difficult to determine where cosmic rays come from?

Cosmic rays are charged particles, which means that they can be deflected by magnetic fields. As a result, they do not travel in straight lines. They curve due to the magnetic fields of Earth and those found in interstellar space. Because they travel in curved paths, we cannot easily trace them back to their point of origin.

5. What causes reddening of starlight? Explain how the reddish color of the Sun’s disk at sunset is caused by the same process.

Small particles, either dust grains in interstellar space or molecules in Earth’s atmosphere, can absorb and scatter light. Both absorption and scattering are more efficient for blue light than for red light. As a result, they cause more extinction of blue light than of red light, so starlight that passes through a region filled with small particles will emerge redder than it was when it entered. In the case of Earth’s atmosphere, the sun appears redder at sunset than midday. Since it is lower in the sky, its light must travel a longer path through the atmosphere, with a greater chance that sunlight will be scattered. Since red light is more likely to be scattered than blue light, the Sun appears increasingly red as it approaches the horizon.

6. Why do molecules, including H₂ and more complex organic molecules, only form inside dark clouds? Why don’t they fill all interstellar space?

Dark clouds are vulnerable to dissociation by ultraviolet light. Most of interstellar space is filled with ultraviolet light from stars, so any molecules that form there are



quickly disrupted. Significant numbers of molecules can build up only in places where the ultraviolet light is blocked, and the only places in interstellar space that meet that requirement are inside dark clouds.



7. Why can't we use visible light telescopes to study molecular clouds where stars and planets form? Why do infrared or radio telescopes work better?

Molecules can only exist in dark clouds where ultraviolet starlight is blocked out. However, these same regions are also very cold because the same photons that destroy molecules are also responsible for heating up the gas. Regions that are dark enough to have molecules are therefore also too cold to emit much at visible light wavelengths. Furthermore, the dust that is responsible for protecting the molecules would also block any visible light from escaping to our telescopes. Both of these problems are diminished or go absent at infrared and radio wavelengths. Colder material does emit infrared and radio light, and the wavelengths are much less subject to extinction by dust.

8. The mass of the interstellar medium is determined by a balance between sources (which add mass) and sinks (which remove it). Make a table listing the major sources and sinks, and briefly explain each one.

Process	Source/Sink	Explanation
Accretion from intergalactic space	Source	Gas falls onto the Milky Way from intergalactic space and is incorporated into the interstellar medium.
Star formation	Sink	Gas in the interstellar medium collapses under its own gravity to form stars.
Stellar evolution	Source	As stars end their lives, they eject mass back into the interstellar medium.

9. Where does interstellar dust come from? How does it form?

Dust forms in the winds coming off stars as they lose mass at the end of their lives, or from condensing in the material from supernova explosions. Dust grains can also grow when they find themselves in dense environments like molecular clouds.

10. The terms H II and H₂ are both pronounced "H two." What is the difference in meaning of those two terms? Can there be such a thing as H III?

H II means hydrogen that has been stripped of its electron (ionized). The Roman numeral I indicates an atom with all its electrons, II means one electron removed, III means two electrons removed, and so on. There is no such thing as H III because that would mean hydrogen with two electrons removed. However, hydrogen only has one electron to start with. In contrast, H₂ means a hydrogen molecule: two hydrogen atoms held together by a bond.

11. Describe the spectrum of each of the following:

- A starlight reflected by dust,
- B a star behind invisible interstellar gas, and
- C an emission nebula.

A. The overall shape of the spectrum is the similar to that of the star: a continuum with some emission or absorption lines superimposed, depending on the star. The spectrum will be slightly altered in that it will contain more blue and less red light than the original stellar spectrum, due to the preferential scattering of blue light. B. The spectrum will look the same as for an unobscured star, except that there will be



narrow absorption lines at certain wavelengths, corresponding to colors that can be absorbed by atoms such as calcium and sodium in the interstellar gas. C. The spectrum of an emission nebula is dominated by emission lines, most prominently the Balmer line of hydrogen, along with helium and other light elements. The continuum will be very faint or entirely undetected.

12. New stars form in regions where the density of gas and dust is relatively high. Suppose you wanted to search for some recently formed stars. Would you more likely be successful if you observed at visible wavelengths or at infrared wavelengths? Why?

Dust is an efficient absorber of visible radiation, and so star-forming regions often cannot be observed at visible light wavelengths. Infrared radiation does penetrate the dust, and so infrared observations are an essential tool for studying regions of star formation.

13. We can detect 21-cm emission from other galaxies as well as from our own Galaxy. However, 21-cm emission from our own Galaxy fills most of the sky, so we usually see both at once. How can we distinguish the extragalactic 21-cm emission from that arising in our own Galaxy? (Hint: Other galaxies are generally moving relative to the Milky Way.)

The answer is by using the Doppler effect. External galaxies are moving relative to ours, and thus, their emission is shifted to a slightly different wavelength. In a spectrum, this makes the 21-cm emission from other galaxies distinguishable from the 21-cm emission from ours.

14. Suppose that you gathered a ball of interstellar gas that was equal to the size of Earth (a radius of about 6000 km). If this gas has a density of 1 hydrogen atom per cm^3 , typical of the interstellar medium, how would its mass compare to the mass of a bowling ball (5 or 6 kg)? How about if it had the typical density of the Local Bubble, about 0.01 atoms per cm^3 ? The volume of a sphere is $V = (4/3)\pi R^3$.

The volume of Earth is $V = (4/3)\pi R^3 = 9.2 \times 10^{26} \text{ cm}^3$, so there are 9.2×10^{26} hydrogen atoms in it at the typical interstellar density. Each atom has a mass $m = 1.7 \times 10^{-27} \text{ kg}$, so the total mass of the ball is therefore $M = Nm = 1.5 \text{ kg}$, just a bit lighter than a bowling ball. At the density of the Local bubble, the number of atoms would be 100 times smaller, making the mass about 15 g.

15. H II regions can exist only if there is a nearby star hot enough to ionize hydrogen. Hydrogen is ionized only by radiation with wavelengths shorter than 91.2 nm. What is the temperature of a star that emits its maximum energy at 91.2 nm? (Use Wien's law from Radiation and Spectra.) Based on this result, what are the spectral types of those stars likely to provide enough energy to produce H II regions?

According to Wien's law, $\lambda_{\text{max}} = 3,000,000/T$, where the wavelength is in nanometers and T is the temperature. The temperature of a star that emits its most intense radiation at 91.2 nm is $3,000,000/91.2 = 33,000 \text{ K}$, which is the temperature of an O star.

No. Using Wien's law, a surface temperature of 50,000 K will produce a peak wavelength, $\lambda_{\text{max}} = b/T = 3,000,000/T$, where the wavelength is in nanometers. $3,000,000/50,000 \text{ K} = 60 \text{ nm}$. This is still significantly longer than the 10.9 nm required to produce OVI.

16. Dust was originally discovered because the stars in certain clusters seemed to be fainter than expected. Suppose a star is behind a cloud of dust that dims its brightness by a factor of 100. Suppose you do not realize the dust is there. How much in error will



your distance estimate be? Can you think of any measurement you might make to detect the dust?

If the brightness decreases by a factor of 100 because of dust, and we cannot detect the dust, then we will estimate that the star is 10 times farther away than it actually is; brightness decreases as the square of the distance. The dust should also redden the star, and so if its color is redder than we would expect from the spectral type that we observe, then we can tell that dust is affecting the brightness of the star.

