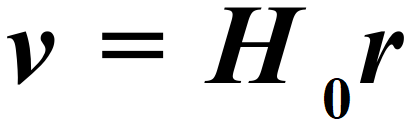
**Worksheet on Origins of the Elements**

1. The Hertzsprung-Russell (H-R) diagrams of an open cluster (the Pleiades) and a globular cluster (M3) are shown below.  
     
    Diagram, engineering drawing

   Description automatically generated  
     
   Which cluster is older? Explain how the H-R diagrams above enable you to deduce this.
2. Describe the nuclear reactions occurring in the cores of:  
     
   (a) stars on the main sequence  
     
   (b) red giants
3. Describe the nature of a line absorption spectrum and identify one type of information we can gain from such a spectrum.
4. In your investigations in this Module, you would have studied the work of Edwin Hubble. Describe Hubble’s work and assess the significance of his conclusions.
5. List 5 processes that led to the transformation of radiation into matter after the Big Bang. Choose one of these and outline the process.  
     
     
     
     
   Questions continue over the page.
6. The spectrum of a star can be used to plot its position on a Hertzsprung-Russell (H-R) diagram, such as the one below.  
     
      
     
   (a) Explain how spectral class assists in the classification of stars.
7. Assess the benefits of drawing an H-R diagram like the one above.
8. Use the H-R diagram above to give the full spectral classification of both our Sun and the star Rigel (located in the top left area of the diagram).
9. **Extension Question:** How can line absorption spectra be used to deduce information about interstellar dust clouds?

**Answers**

1. M3 is older because as the diagrams show: The more luminous (more massive) stars are no longer on the main sequence of M3. Its main sequence has “burned down like a candle” as the more massive stars have evolved into the red giant and supergiant region. The Pleiades H-R diagram shows more luminous (massive) stars still on its main sequence. Thus, it is young. There are no red giants or supergiants in the Pleiades, indicating that it is a very young cluster.  
     
   1. Hydrogen is being fused into helium in the core of every main sequence star. These reactions are self-sustaining and require core temperatures in excess of several million kelvin. The more massive stars on the main sequence, the hotter stars with core temperatures above 16 million K, “burn” hydrogen mainly via the carbon-nitrogen-oxygen (or CNO) cycle. The less massive stars, the cooler stars with core temperatures below 16 million K, use the proton-proton chain reaction as the main energy producing reaction.
   2. In red giants, the helium rich inner core becomes compressed, and at about 100 million K there are enough helium nuclei fusing for the sequence to become self-sustaining. This is called the triple alpha reaction which converts helium to carbon and oxygen. The hydrogen rich shell around the inner core undergoes sustained hydrogen to helium fusion (from a temperature of around 10 million K), this includes some p-p chain & CNO cycle reactions. In a high-mass red giant (mass > 2 to 3 solar masses), with a hotter core, helium burning begins gradually whereas in a low-mass red giant (mass < 2 to 3 solar masses), it begins very suddenly, in a process called the helium flash.
2. A line absorption spectrum is seen as a series of thin black vertical lines across the background continuous spectrum of the light from the star. Each black lines indicates a particular wavelength (and hence energy) at which light emitted from the star’s core is absorbed by cooler gas in the path of the light. As each element has a unique set of wavelengths at which it absorbs light energy, its “spectral fingerprint’, measurement of these absorption wavelengths enables the gases in the star’s atmosphere to be identified.
3. In 1924, Edwin Hubble used Henrietta Leavitt’s Cepheid variable method for measuring large distances, to show that the nebula Andromeda was a separate star system (galaxy) to our Milky Way and that our galaxy was just one of many in the universe.  
     
   Edwin Hubble and Milton Humason photographed the spectra of many galaxies with the 2.5 m telescope on Mount Wilson in California. They found that most galaxies show a red shift in their spectrum. From the redshifts, Hubble used the Doppler formula to calculate the speed of recession of each galaxy.  
     
   Next, by using Leavitt’s method again, Hubble & Humason were able to determine the distance to each galaxy. When they plotted speed versus distance for the galaxies under study, Hubble & Humason found a direct correlation between the distance to a galaxy and its red shift: The more distant the galaxy, the greater its red shift and therefore the more rapidly it is receding from us.  
     
   Hubble concluded that the universe is expanding uniformly and today this universal recessional movement is referred to as the Hubble flow. Hubble’s discovery is extremely important because: (i) it greatly improved our understanding of the universe and allowed further investigations to start from an accurate baseline; and (ii) a plot of the Hubble formula , enables the Hubble constant, , the rate at which the universe is expanding, to be calculated. Knowing the Hubble constant also enables an estimate of the age of the universe, which is equal to the reciprocal of the Hubble constant.
4. Processes: (i) Expansion & cooling of universe; (ii) cosmic inflation; (iii) photon collisions resulting in particle pair production; (iv) symmetry breaking; and (v) nucleosynthesis.  
     
   Symmetry breaking: In the first 10-43 second of the existence of the universe, the four fundamental forces of nature existed as a single, unified force and the temperature was greater than 1032 K. As the temperature decreased, certain critical temperatures were reached where phase transitions occurred. At some of these phase transitions, symmetry breaking occurred. Symmetry breaking means that as each force condensed from the single unified force, it acquired the specific characteristics that it displays today. So, for instance, as the strong nuclear force condensed, it became able to combine nucleons and quarks together strongly enough to eventually produce the nuclei and atoms we see today. Without the strong nuclear force being exactly as it is today, matter as we know it may never have formed from the radiation in the early universe. Without gravity, stars and galaxies would never have formed and life as we know it would not exist. Each of the symmetry breaking events helped in some way to transform radiation into matter.  
     
   1. Spectral classes summarize key features of stellar spectra such as colour, surface temperature and chemical composition. They bring order to the huge variety of different stellar spectra astronomers have discovered. Each spectral class (O, B, A, F, G, K, M, L, T) refers to a set range of stellar colour, temperature and spectral line features. Each spectral class is further sub-divided into finer steps called spectral types. These are indicated by adding a number from 0 to 9 after the appropriate letter for the spectral class. The “0” is the hottest spectral type and the “9” is the coldest. Our Sun, for example, has spectral class and type of G2.
   2. The Hertzsprung-Russell (H-R) diagram is one of the most important in astronomy because of its ability to summarize so many trends so efficiently and because of its usefulness in helping us to understand the evolution of stars. On an H-R diagram such as the one in this question, astronomers describe stars by giving both a spectral class and a luminosity class. The spectral class indicates the star’s surface temperature and the luminosity class its luminosity. (The luminosity class depends on the width of certain absorption lines in the star's spectrum, which vary with the density of the atmosphere and so distinguish giant stars from dwarfs.) After constructing such an HR diagram for a group of stars, astronomers can estimate many important stellar properties including diameter, mass, age, and evolutionary state.
   3. The Sun is a G2 V star.  
        
      Rigel is a B8 Ia star  
        
      (Give yourself a little leeway on the spectral type – 2 or 3 for the Sun and somewhere around 7 to 9 for Rigel, would be acceptable from my H-R diagram.)
5. **Extension:** If a dust cloud exists between the Earth and a star, then the elements in the cloud will imprint their own absorption lines onto the star’s spectrum. These additional lines will usually be much thinner and fainter (ie less intense) than those from the stellar atmosphere. This means the lines added to the stellar spectrum are easy to identify and provide information about the elements and elemental densities in the gas clouds. (The spectral lines from the stellar atmosphere are widened by pressure (collisional) broadening.)