# Norwegian Olympiad on Astronomy and Astrophysics

## Problem set (and solutions) for Round I

2023/2024 school year

Date: Any date during week 41 – 44 (9 October – 5 November 2023)

*Allowed aids: Calculator, pencil/pen and physical constants and formulas given below. Time: 90 minutes*

*This is a multiple choice problem set. There are four possible answers for each problem - A, B, C og D. Use the answer sheet at the end of the problem set to mark the letter corresponding to your chosen answer. There is only a single correct answer for each problem and all problems yield the same number of points. Zero points are given for a problem if more than one answer is marked. Wrong answers do not yield negative points.*

*The problem set has 10 pages, and there are 22 problems.*

*Good luck!*

---

Constants and formulas:

- Apparent magnitude: $m = -2.5 log(F/F_0)$
- Hubble's law: $v = H_0 d$, $H_0 \approx 73$ km/s/Mpc
- Doppler formula: $v/c = (\lambda - \lambda_0)/\lambda_0$
- The Rayleigh criterion: $= 1.22 \cdot \lambda/D$ rad
- Speed of light = 299792458 m/s
- 1 parsec (pc) ≈ 3.26 light years
- 1 Astronomical Unit (AU) ≈ $1.5 \cdot 10^{11}$ m
- Newton's law of gravity: $F_G = GmM/r^2$, $G \approx 6.67 \cdot 10^{-11}$ $m^3/kg/s^2$
- Wien law: $\lambda_{max} = b/T$, $b \approx 2.9 \cdot 10^{6}$ nm·K
- Stefan-Boltzmann's law: $F = \sigma T^4$, $\sigma \approx 5.67 \cdot 10^{-8}$ $W/m^2/K^4$

1) If you go outside on a very clear night with otherwise ideal viewing conditions, approximately how many stars would you be able to see with the naked eye?

**a) 2000-3000**
b) 10 000-12 000
c) 30 000-40 000
d) uncountably many

**Solution: a)** There are actually about 5000 distinct stars that one can see, but only half of these can be seen at any given time and place, where a lot of estimates put this number at about 2500.

2) In August 2023, we could experience something called the "Blue Moon" that happens once every two or three years. What is this phenomenon?

a) The Moon appears to have a blue tint as a result of light scattering differently due to atmospheric changes
b) A colloquial name for a partial lunar eclipse, when the Moon moves into Earth's shadow.
**c) A thirteenth full moon in a single year that happens because of the Moon actually taking less than a month to complete a cycle.**
d) An astrological term signifying the beginning of the Aquarius part of the Zodiac.

**Solution: c)** The Moon takes 29.5 days to complete a cycle of all its phases, which means 354 days for 12 cycles. This is obviously less than the 365 days we have in a year, which results in there being an extra full moon every two or three years.

3) Given that the last appearance of Halley's comet in our sky was recorded in 1986, when can we expect to experience this rare occurrence again?

a) 2041
**b) 2061**
c) 2081
d) 2101

**Solution: b)** The orbital period of Halley's comet is about 76 years.

4) In July this year, NASA lost contact with Voyager 2 when a mistake in commands made the spacecraft point away from our planet by a mere 2 degrees. To try and regain contact with it, NASA had to "shout" commands into space and hope they were received. How much time did they approximately have to wait for confirmation that the command was received by the spacecraft, i.e. sending the signal and getting the response back? At the time of communication loss, Voyager 2 was 135AU away from Earth.

a) 48 minutes
b) 19 hours
**c) 37 hours**
d) 3 days

**Solution: c)** Given the speed of light to be $3*10^8$ m/s and 1AU = $1.5*10^8$ km, the time is simply computed by $(135 * 1.5 * 10^8) / (3 * 10^8 * 3{,}6)$ which turns out to be 18,75 hours. This needs to be multiplied by a factor of 2, since the command needs to get to Voyager 2, and then back to the Earth.

5) What is the Great Red Spot?

a) The biggest crater on Mars' surface.
b) The area in the Milky Way with the highest concentration of Red Dwarves.
**c) A reddish storm on Jupiter, three times the size of our planet.**
d) The largest change in wavelength a photon can exhibit as a result of gravitational redshift.

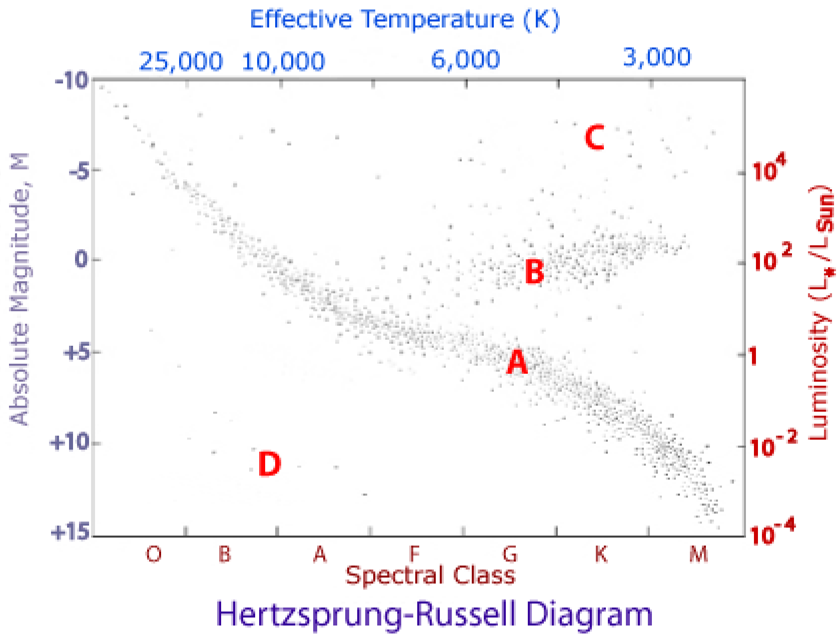
**Solution: c)**

6) Given that the cosmic microwave background radiation has a wavelength of 1.9mm at its peak, and it behaves like a black body, approximately what temperature (in Kelvin) does this correspond to?

a) 0.002K
**b) 2.73K**
c) 30K
d) 273.15K

**Soluction: b)** According to Wien's displacement law with constant of proportionality $b = 2.898*10^{-3}$ m*K, we obtain 2.73K .

7) About 4.5 billion years from now, our Sun will approach the end of its lifetime. Where on the HR diagram will it ultimately end up when that time comes?




a) A - Main Sequence
b) B - Giants
c) C - Super Giants
**d) D - White Dwarfs**

**Solution: d)** The Sun is currently on the main sequence, marked A. When it starts dying, it will first become a Red Giant, or B on the diagram, and then finally go into the White Dwarf stage, which is marked with D on the HR-diagram.

8) If Kepler's Third Law that describes the revolution period of a planet around a star is given by the equation $T^2 = Kr^3$, where K is a constant, and the inverse square law of gravitation is $F = G * (M*m) / r^2$, which of the following represents the relationship between the constants K and G? You may assume that the planet orbits the star in a perfect circle.

a) $K = G$
b) $K = G^{-1}$
**c) $K = (4\pi^2) / (GM)$**
d) $K = (G * 4\pi^2) / M$

**Solution: c)** This problem can be solved by simply using dimensional analysis, but a more analytical approach is also possible by doing the following:

- Given the only force in a rotational movement is the gravitational force, the radial velocity is given by solving:
  - $mv^2/r = G * (M * m) / r^2$
    - $v = sqrt(GM / r)$
- The period in rotational motion is simply given by
  - $T = (2*\pi*r) / v$
- Inserting the expression for v and some algebra give $K = (4\pi^2) / (GM)$

9) It is a nice sunny day where you are in Norway, but there is some haze along the horizon. Around noon you look up at the blue daytime sky and notice a waning (third quarter) half moon. What time of the year is it?

**a) Fall (around fall equinox)**
b) Winter (around winter solstice)
c) Spring (around spring equinox)
d) Summer (around summer equinox)

**Solution: a.** The students may have noticed that the third quarter moon is fairly frequently visible in the daytime fall sky before and around noon. Detailed explanation: A third quarter moon will be located about 90 degrees west of the sun. Hence, relative to the background stars, the moon will appear approximately at the location where the sun was three months earlier. At fall equinox the third quarter moon will therefore be at the location of the sun during summer solstice. At noon (when the sun appears due south) the third quarter moon will then ber at an hour angle of (90 degrees / (360/24) degrees per hour) = 6 hours (i.e. it is six hours since the moon passed the meridian). The moon will then still be well above the horizon (having about the same location as the sun at summer solstice around 7PM). Similar arguments will show that for alternatives b) and d) the moon will be very close to the horizon and at best be visible very low in the sky where it is easily lost in the haze. For alternative c) the moon will clearly be below the horizon.

10) What happened when the cosmic microwave background radiation was released?

a) Ignition of the first stars ~50-100 million years after the Big Bang.
**b) Combination of nuclei and electrons into neutral atoms, dramatically reducing the number of free electrons, 400,000 years after the Big Bang.**

c) The first gamma-ray bursts occurred ~50-100 million years after the Big Bang.
d) Transmission of radio signals from artificial satellites in orbit around the earth (1957– )

**Solution: b.** When the universe expanded and cooled, atomic nuclei and electrons could combine into neutral atoms. This drastically reduced the number of free electrons on which photons could scatter. After this time, the mean free path of photons was long enough that the universe became transparent, and we observe these photons today as the cosmic microwave background radiation.

11) If a star with a parallax angle of 1/3600 degree is at a distance of 1 parsec, how far away is a star with a parallax angle of 1/7200 degree?
a) 0.5 parsec
b) 1 parsec
**c) 2 parsec**
d) 5 parsec

**Solution: c.** The distance is inversely proportional to the parallax angle

12) If we shrink the earth while keeping the earth's mass unchanged, what will happen to the length of the day?
a) The length of the day does not change, but the year becomes shorter
b) The length of the day increases
**c) The length of the day decreases**
d) The length of the day does not change, but the year becomes longer

**Solution: c.** Since angular momentum is conserved, the earth's rotational speed will increase as the earth shrinks, making the day shorter. The orbital period around the sun is not affected.

13) Two light sources, A og B, emit light in all directions. They are placed at distances r and 2r, respectively, from a detector that measures the same flux from both sources ($F_A/F_B = 1$). If A is moved to a distance 2r and B is moved to a distance 3r, what is the new relationship between $F_A$ and $F_B$ ?

a) $F_A/F_B = 2/3$
**b) $F_A/F_B = 9/16$**

c) $F_A/F_B = 4/9$
d) $F_A/F_B = 3/4$

**Solution: b.** Using the inverse square law for the dependence of flux with distance, we find that $F_{A,\ new} = (½)^2 F_{A,\ old}$ and $F_{B,\ new} = (⅔)^2 F_{B,\ old}$ . Given that the old ratio is $F_{A,\ old}/F_{B,\ old} = 1$ then the new ratio is $F_A/F_B = 9/16$.

14) A galaxy is moving away from us at a velocity of 3000 km/s. Approximately how far away is the galaxy? (Mpc = Megaparsec)

a) 7 Mpc
b) 22 Mpc
**c) 41 Mpc**
d) 730 Mpc

**Solution: c.** The solution is found by using Hubble's law

15) There is a point between the earth and the moon where the gravitational forces from both bodies are the same, but pointing in opposite directions. Where is this point located, given that the mass of the earth is about 81 times the mass of the moon?

a) 1/10 of the way from the earth towards the moon
b) 1/9 of the way from the earth towards the moon
c) 1/9 of the way from the moon towards the earth
**d) 1/10 of the way from the moon towards the earth**

**Solution: d.** Using Newton's law of gravity we find that the earth must be 9 times further away than the moon at this point.

16) The angular resolution of a telescope is given by $\sim\frac{\lambda}{D}$, where D is the diameter of the telescope and **λ** is the observed wavelength. How will change the resolution if we observe with a fixed lambda, varying the diameter?

a) The resolution will not change if we vary the diameter.

b) **A smaller diameter telescope has worse resolution than a larger diameter telescope.**
c) A smaller diameter telescope has better resolution than a larger diameter telescope.
d) The resolution of a telescope only changes if we vary the observed wavelength ($\lambda$).

**Solution: c.** Following the given formula, if $\lambda$ is fixed, for a larger (smaller) diameter we will get a larger (smaller) angular resolution.

17) Which process occurs inside the cores of all main sequence stars?

a) Fusion of helium into carbon
b) Fission of uranium into iron and oxygen.
c) Fusion of carbon into nitrogen and oxygen.
d) **Fusion of hydrogen into helium.**

**Solution: d.** Fusion of hydrogen into helium

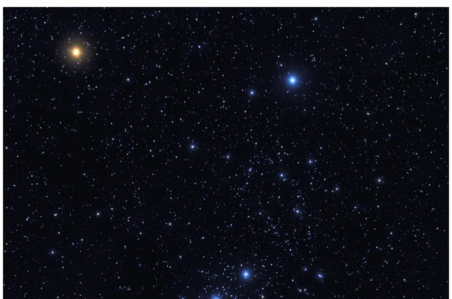
18) What star is aligned with the rotation axis of the Earth, i.e, indicates the North?

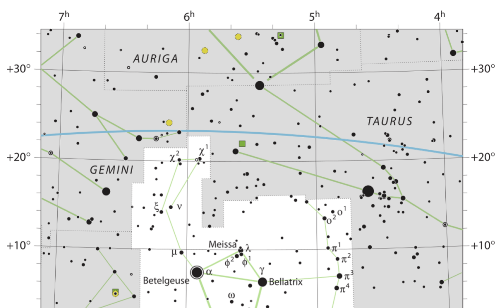
a) **Polaris**
b) Betelgeuse
c) Rigel
d) Vega

**Solution: a.** Polaris.

19) What constellation is depicted in the images below?

a) Cassiopeia
b) Ursa Major
c) Ursa Minor



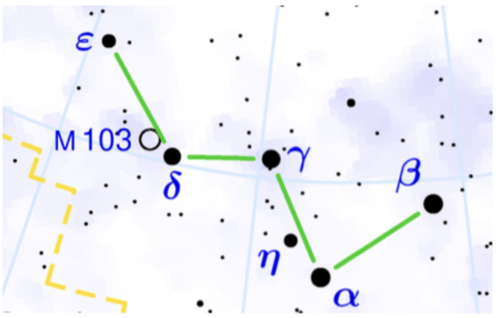


**d) Orion**

**Solution: d.**

20) What constellation is depicted in the images below?

**a) Cassiopeia**
b) Ursa Major
c) Ursa Minor
d) Orion




**Solution: a.**
21) Where do you have to point your camera to obtain an image as the one below in the north hemisphere? (it is a composed image).

**a) Polaris**
b) Antares

c) Vega
d) Sirius

**Solution: a.** It is needed to point towards Polaris because it coincides with the rotation axis of the Earth. Hence, all the other stars move around it tracing “startrails” (the concentric rings around Polaris).

22) What produces the Northern Lights?

a) Gamma ray bursts from Black Holes
b) Cosmic rays
**c) Solar wind**
d) Asteroids disintegration

**Solution: c.**