TAP 704- 7: Red shifts of quasars

Red shifts from the expansion of the Universe

The questions below are about the red shift of light from quasars ('quasi-stellar radio source' abbreviated to QSR). You will need to know that the change in the wavelength of the light is due to the expansion of the Universe. Thus the ratio:

$$\frac{\lambda_{received}}{\lambda_{sent}}$$

is equal to the factor by which the Universe has expanded during the time of travel of the light. The red shift z is usually expressed as:

$$z = \frac{\text{change in wavelength}}{\text{original wavelength}} = \frac{\Delta\lambda}{\lambda}.$$

Since

$$\lambda_{received} = \lambda_{sent} + \Delta\lambda,$$

the ratio

$$\frac{\lambda_{received}}{\lambda_{sent}} = \frac{\lambda_{sent} + \Delta\lambda}{\lambda_{sent}} = 1 + z$$

Thus for a red shift z the corresponding expansion of the Universe is $z + 1$.

The first quasar identified

In 1962, Australian radio astronomers got an accurate position for one of the sources in the Third Cambridge Catalogue of radio sources. Its catalogue number was 3C273. They did it by watching 3C273 being eclipsed by the edge of the Moon. Optical telescopes picked it up as a very faint star-like object with a faint 'jet' coming out of it. Opinion was generally that it was a peculiar nearby star. But when Maarten Schmidt took its spectrum, he recognised the spectrum as part of the hydrogen spectrum, shifted to longer wavelengths by 15.8%.

1. One of the hydrogen lines Schmidt observed normally has wavelength 486 nm. What wavelength did Schmidt observe it to have?

2. Another hydrogen line has wavelength 434 nm. What wavelength does it have, red shifted by the same fraction

3. By what factor has the Universe expanded since light now reaching us left 3C273?

Another quasar, already seen

Earlier, another source, 3C48 had been identified with an even fainter ‘star’. Its spectrum was reported as showing 'a combination of lines unlike that of any other star known'. Given Schmidt’s identification of red shifted lines in the 3C373 spectrum, others quickly identified lines in the 3C48 spectrum that had an even bigger red-shift, of 36.8%

4. If a line in the 3C48 spectrum appeared in the red at 650 nm, what would its original wavelength have been? Is this in the visible region?

5. If the scale of the Universe is now about 15 billion light years, what was its scale when the light left 3C48?

Red shifts make invisible radiation visible

Hydrogen atoms emit strongly in the ultraviolet. One such line is at wavelength 122 nm. This line was found appearing in even more distant quasars at the far blue end of the spectrum, wavelength about 360 nm.

6. What is the percentage red shift in this case?

7. What was the scale of the Universe when this light was emitted?

Extreme red shifts

For a time it was thought that there were no quasars to be found beyond 200% red shift. However, since then red shifts discovered have reached as high as a factor 5.

8. In what part of the spectrum would a photon now seen in the visible have started out, if the red shift is 5?

9. By what factor has the photon energy decreased in this case?

10. By what factor has the Universe expanded in this case?

Hints

1. Remember $z = \Delta\lambda/\lambda$.
2. Remember $z = \Delta\lambda/\lambda$.
3. Think of the ratio of the wavelengths
4. Think of the ratio of the wavelengths, again
5. Work from $1+z$
6. Find the change in wavelength first
7. Use data from question 5
8. Use the ratio $z + 1$. Guess a ‘visible wavelength’
9. Use $E = hf$
10. Try $z + 1$ again

Practical advice

These are intended as simple practice questions about the cosmological red shift. For that reason, no 'recession velocities' are calculated. The red-shift is here determined by the expansion of the universe. The questions give practice in calculating red shifts z and expansion ratios 1 + z, with some interesting information about when and how these discoveries were made.

Be aware of how easy it is to mistake whether to use $z = \frac{\Delta\lambda}{\lambda}$ and $\frac{\lambda_{received}}{\lambda_{sent}} = 1 + z$

Alternative approaches

You may well find up-to-date magazine articles about cosmological red shifts, which could be used to generate similar questions.

Social and human context

It is remarkable that these very distant objects, giving fundamental insights into the nature of the universe, were first picked up by radio astronomy, soon after it emerged following developments in radar in World War II.

Answers and worked solutions

1. z = 15.8% = 0.158 = $\Delta\lambda/\lambda$. Thus $\Delta\lambda$ = 0.158 × 486 nm = 76.8 nm. The new wavelength is 486 nm + 77 nm = 563 nm.

2. z = 15.8% = 0.158 = $\Delta\lambda/\lambda$. Thus $\Delta\lambda$ = 0.158 × 434 nm = 68.6 nm. The new wavelength is 434 nm + 69 nm = 503 nm.

3. The expansion factor is z+1, with z = 0.158. Thus the expansion factor is 1.158.

4. If z = 0.368 then

   $$\frac{\lambda_{received}}{\lambda_{sent}} = 1 + z = 1.368\,.$$

   Thus $\lambda_{sent} = \lambda_{received}/(1+z)$, or λ_{sent} = 650 nm/1.368 = 475 nm. This is in the blue region of the spectrum.

5. The scale is 15 billion light years divided by 1 + z = 1.368, giving just under 11 billion light years.

6. Red shift z = (360 nm – 122 nm) /122 nm = 1.95 or nearly 200%.

7. Expansion ratio = 1 + z = 1 + 1.95 ≈ 3. Scale of universe = 15 billion light year/3 = 5 billion light years.

8. Take the centre of the visible region as 500 nm. Then the original wavelength is

500 nm / (z + 1) = 500 nm/5 = approximately 80 nm, in the very hard ultra-violet region.

9. Since E = hf and f = c/λ the energy has decreased by the same factor as the wavelength increased, a factor 6

10. Expansion ratio is z + 1, so the universe has expanded by a factor of 5 + 1 = 6

External References

This activity is taken from Advancing Physics, chapter 12, 95S