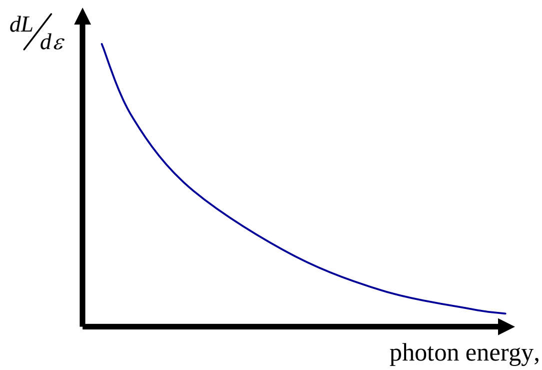
University of Glasgow

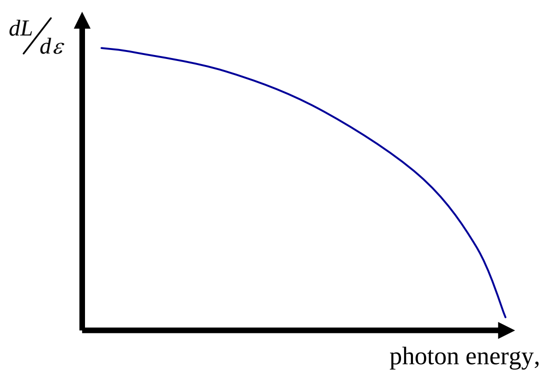
Department of Physics and Astronomy

High Energy Astrophysics II: Example Sheet 2

1. The figure below sketches the differential luminosity of an X-ray source as a function of photon energy. Sketch the 1st, 2nd and 3rd derivatives of this curve with respect to photon energy, and hence verify that the X-ray source could be emitting thermal bremsstrahung.



2. The figure below sketches the differential luminosity of another X-ray source. Explain carefully why this source *cannot* be 100% thermal bremsstrahlung. Could it be a source of non-thermal bremsstrahlung?



3. Verify the result given in Eq. (3.9), that the magnetic field for which the total energy of a synchrotron source is minimised satisfies $B = B_0 = \left(\frac{3\beta}{4}\right)^{2/7}$ where $\beta = \frac{3\mu_0^2 c}{Q_T}\left(\frac{3em_e}{4\pi}\right)^{1/2}\left(\frac{L_S}{\nu^{1/2}V}\right)$

4. Show, in turn, that $E_{\min} = \frac{V}{2\mu_0} \times \frac{7}{3} B_0^2$, and hence that $\frac{E}{E_{\min}} = \frac{3}{7}\left(\frac{B}{B_0}\right)^2 + \frac{4}{7}\left(\frac{B_0}{B}\right)^{3/2}$

5. Verify that when $B = B_0$, $E_B = \frac{3}{7} E_{\min}$, and hence that $E_B = \frac{3}{4} E_e$

6. Compute the value of $E/E_{\min}$ when $B = \frac{1}{10} B_0$ and when $B = 10B_0$

7. The Crab nebula is a strong X-ray source. Assuming that the synchrotron emission originates from a spherical volume of radius $r = 1.5\,\mathrm{pc}$, estimate the value of β at an energy of 1 keV given the following data: $L_S = 4.9\times10^{30}\,\mathrm{W}$, $c = 3\times10^{8}\,\mathrm{ms^{-1}}$, $\mu_0 = 1.26\times10^{-6}\,\mathrm{Hm^{-1}}$, $e = 1.6\times10^{-19}\,\mathrm{J}$, $m_e = 9.1\times10^{-31}\,\mathrm{kg}$, $h = 6.63\times10^{-34}\,\mathrm{Js}$.

8. Hence verify that the magnetic field corresponding to minimum total energy for the Crab is $B_0 \sim 9\times10^{-9}\,\mathrm{T}$, and that the corresponding total energy is $E_{\min} \sim 3\times10^{40}\,\mathrm{J}$

9. Show that the constant in Eq. (3.14), evaluated in S.I. units, is approximately 1.6×10^{6}. Hence, verify that for a synchrotron decay timescale $\tau_s \sim 1000\,\mathrm{yr}$ and a synchrotron frequency $\nu_s \sim 10^{14}\,\mathrm{Hz}$, the corresponding magnetic field $B \sim 3\times10^{-8}\,\mathrm{T}$.

(Note: the question below concerns the synchrotron emission at radio frequencies from a radio galaxy. Although this question does not deal directly with X-ray emission, the formulae applied here for radio synchrotron emission would also hold for X-ray synchrotron in a more energetic source – and the synchrotron electrons that produce the radio emission are certainly very high energy particles! This question also appears in the Galaxies 2 example sheets and is reproduced here for the benefit of students not taking that course – and to encourage you all to look for the overlaps between your different astrophysics courses as a helpful aid to your exam revision).

10. The radio galaxy Centaurus A lies at a redshift of $z = 0.00157$ and delivers a flux density of $S_\nu = 912\,\mathrm{Jy}$ at a radio frequency of 1400 MHz.

    a) Assuming that the radio spectrum of Centaurus A is a power law, $S_\nu \propto \nu^{-0.6}$, estimate the total radio flux of Centaurus A in the frequency range $10^{7}\,\mathrm{Hz}$ to $3\times10^{9}\,\mathrm{Hz}$.

    b) Hence determine the total radio luminosity of Centaurus A in this frequency range. Compare your answer with the total optical luminosity of the Milky Way.

    c) If the total energy stored in each radio lobe of Centaurus A is $E_{\mathrm{tot}} \approx 10^{50}\,\mathrm{J}$, estimate the time taken to radiate away this energy, given the radio luminosity of the galaxy.

    d) Modelling each radio lobe as a sphere of radius 10 kpc, and assuming equipartition (i.e. $E_{\mathrm{tot}} = E_{\mathrm{particle}} + E_{\mathrm{magnetic}} \sim 2E_{\mathrm{magnetic}}$), estimate the strength of the magnetic field in the radio lobes of Centaurus A.

    e) Hence estimate the Lorentz factor of electrons producing synchrotron radio emission from Centaurus A at the frequency of 1400 MHz.