Problem 1 [Fernow Prob. 2.2]

What is the expected mean energy loss of 50-GeV/c protons in beryllium? How much is this result affected by the density effect correction?

Problem 2 [Fernow Prob. 2.3]

Consider a 10-GeV/c K^- beam in liquid hydrogen. What is the maximum kinetic energy of delta rays produced by the beam? How many delta rays with kinetic energy greater than 100 MeV are produced in 2 cm?

Problem 3 [Fernow Prob. 2.4]

Calculate the Landau distribution function numerically and plot $f_L(\lambda)$ versus λ.

Problem 4 [Fernow Prob. 2.5]

Find the most probable energy loss of 100 GeV/c π^- in copper. What is the probability of observing an energy loss of half of this amount and twice this amount?

Problem 5 [Fernow Prob. 2.14]

Estimate the critical angle for channeling of a 20 GeV/c π^- in tin.

Problem 6 [Grupen Prob. 1.2]

The energy loss of TeV muons in rock can be parametrised by

$$-\frac{1}{\rho}\frac{dE}{dx} = a + bE$$

where a stands for a parametrisation of the ionisation loss and the b term includes bremsstrahlung, direct electron-pair production and nuclear interactions ($a \simeq 2$ MeV/(g/cm^2), $b \simeq 4.4\ 10^{-6}$ (g/cm^2)$^{-1}$). Estimate the range of a 1 TeV muon in rock.

Problem 7 [Grupen Prob. 1.7]

The production of δ rays can be described by the Bethe-Bloch formula. To good approximation the probability for δ-ray production is given by:

$$\phi(E)dE = K\frac{1}{\beta^2}\frac{Z}{A}\frac{x}{E^2}dE$$

where

$K = 0.154$ MeV/(g/cm^2),

$Z, A =$ atomic number and mass of the target,

$x =$ absorber thickness in g/cm^2

Work out the proability that a 10 GeV muon produces a δ ry of more than $E_0 = 10$ MeV in an 1 cm argon layer (gas at STP).

Problem 8 **[Knoll Prob. 2.2]**

With the aid of the pstar database, estimate the energy remaining in a beam of 5 MeV protons after passing through 100 μm of silicon.

Problem 9 **[Knoll Prob. 2.3]**

Find the approximate energy loss of 1 MeV alpha particles in a thickness of 5μm of gold.

Problem 10 **[Knoll Prob. 2.4]**

Estimate the range of a 1 MeV electrons in aluminum.

Problem 11 **[Knoll Prob. 2.5]**

Calculate the energy of a 1 MeV gamma-ray photon after Compton scattering through 90^o.

Problem 12 **[Knoll Prob. 2.6]**

Give an estimation of the ratio of the probability per atom for photoelectric absortion in silicon to that in germanium.

Problem 13 **[Knoll Prob. 2.7]**

Indicate which of the three major interaction processes is dominant in the following situations:

(a) 1 MeV gamma-ray in aluminum

(b) 100 keV gamma-ray in hydrogen

(c) 100 keV gamma-ray in iron

(d) 10 MeV gamma-ray in carbon

(f) 10 MeV gamma-ray in lead

Problem 14 [Knoll Prob. 2.8]

Calculate the mean free path of 1 MeV gamma-ray in sodium iodine (specific gravity=3.67)

Problem 15 [Knoll Prob. 2.10]

For 140 keV gamma rays, the mass attenuation coefficients for hydrogen and oxygen are 0.26 and 0.14 cm^2/g, respectively. What is the mean free path in water at this energy?

Problem 16 [Turner Prob. 5.4]

(a) Calculate the maximum energy that a 3-MeV alpha particle can transfer to an electron in a single collision.

(b) Repeat for a 100-MeV pion.

Problem 17 [Turner Prob. 5.5]

What would be the relationship between the kinetic energies T_p and T_d of a proton and a deuteron that could transfer the same maximum energy to an atomic electron?

Problem 18 [Turner Prob. 5.6]

Which can transfer more energy to an electron in a single collision, a proton or an alpha particle? Explain.

Problem 19 [Turner Prob. 5.7]

Calculate the maximum energy that a 10-MeV muon can lose in a single collision with an electron.

Problem 20 [Turner Prob. 5.10]

If the macroscopic cross section for a charged particle is 62 μm^{-1}, what is the average distance of travel before having a collision?

Problem 21 [Turner Prob. 5.13-5.16]

Compute the mean excitation energy of:

(a) Be

(b) Al

(c) Cu

(d) Pb

(f) C_6H_6

(g) SiO_2

(h) Air. Assume a compositon of 4 parts N_2 to 1 part O_2 by volume.

Problem 22 [Turner Prob. 5.18-5.21]

Bethe-Bloch formula can be written as:

$$-\frac{dE}{dx} = K\rho\frac{Z}{A}\frac{z^2}{\beta^2}\left[\frac{1}{2}\ln\left(\frac{2m_e\gamma^2\beta^2T_{max}}{I^2}\right) - \beta^2\right]$$

with $K = 4\pi N_a r_e^2 m_e c^2 = 0.307075\ MeV\frac{cm^2}{g}$, can be written as

$$-\frac{dE}{dx} = K\rho\frac{Z}{A}\frac{z^2}{\beta^2}\left[F(\beta) - \ln I_{eV}\right]$$

Find the expression of $F(\beta)$. Calculate the values of $F(\beta)$ for

(a) a 52 MeV proton

(b) a 500 MeV alpha particle

(c) a 5 MeV deuteron

(d) a 100 MeV muon

(e) a 10 GeV muon

Problem 23 [Turner Prob. 5.22]

Calculate the stopping power in water for:

(a) a 7-MeV proton,

(b) a 7-MeV pion,

(c) a 7-MeV alpha particle.

Problem 24 [Turner Prob. 5.23]

Using the pstar database for the stopping power of water, estimate the stopping power of Lucite ($\rho = 1.19\text{g cm}^{-3}$) for a 35-MeV proton.

Problem 25 [Turner Prob. 5.24]

(a) By what factor can the stopping power for alpha particles exceed that for protons?

(b) By what factor does the maximum alpha-particle stopping power exceed the maximum proton stopping power?

(c) Why is the answer to (b) not 4, the ratio of the square of their charges?

(d) What is the value of maximum stopping power of pions?

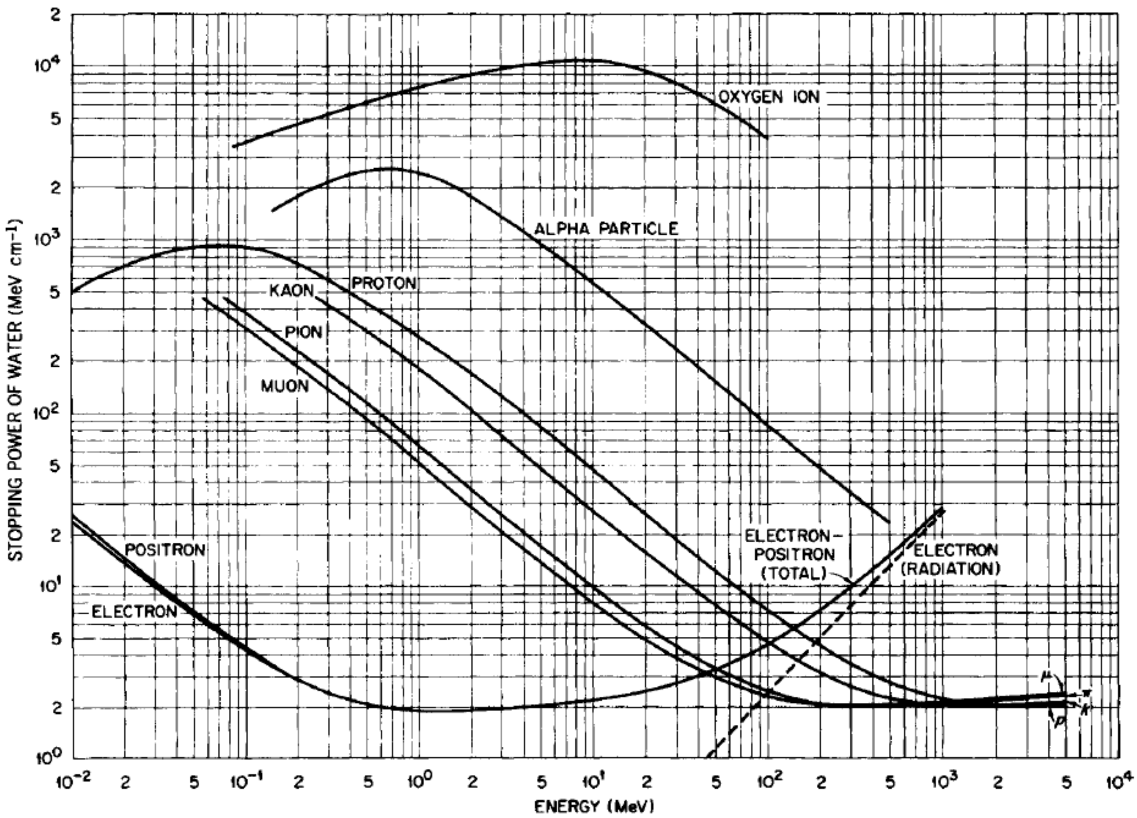


Fig. 5.6 Stopping power of water in MeV cm^{-1} for various heavy charged particles and beta particles. The muon, pion, and kaon are elementary particles with rest masses equal, respectively, to about 207, 270, and 967 electron rest masses. (Courtesy Oak Ridge National Laboratory, operated by Martin Marietta Energy Systems, Inc., for the Department of Energy.)

Problem 26 [Turner Prob. 5.25]

Determine the minimum energy that a proton must have to penetrate 30 cm of tissue, the approximate human body.

Problem 27 [Turner Prob. 5.26]

What is the range of a 15-MeV $^3He^{2+}$ particle in water?

Problem 28 [Turner Prob. 5.27]

Write a formula that gives the range of a π^+ at a given velocity in terms of the range of a proton at that velocity.

Problem 29 [Turner Prob. 5.28]

How much energy does an alpha particle need to penetrate the minimal protective epidermal layer of skin (thickness ~7 mg cm^{-2})?

Problem 30 [Turner Prob. 5.30]

A proton and an alpha particle with the same velocite are incident on a target. Which will penetrate to a greather depth?

Problem 31 [Turner Prob. 5.33]

^{239}Pu emits a 5.16 MeV alpha particle. What is its range in cm in:

(a) muscle,

(b) bone of density 1.9 g cm^{-3},

(c) air at 22^{o}C and 750 mm Hg,

Problem 32 [Turner Prob. 6.3-6.4]

Calculate the collisional stopping power of water for 600-keV electrons and positrons.

Problem 33 [Turner Prob. 6.8]

(a) From figure 6.2, estimate for a 100-eV electron the probability that a given energy-loss event will result in excitation rather than ionization , in water.

(b) What fraction of the collisions at 100 eV are due to elastic scattering?

Problem 34 [Turner Prob. 6.10]

Estimate the critical energy for electrons in (a) Be, (b) Cu and (c) Pb.

Problem 35 [Turner Prob. 6.11]

What is the ratio of the collisional and radiative stopping power of Al for electrons of energy (a) 10 keV, (b) 1 MeV and (c) 100 MeV?

Problem 36 [Turner Prob. 6.12]

Estimate the radiation yield for 10-MeV electrons in (a) Al, (b) Fe and (c) Au.

Problem 37 [Turner Prob. 6.18]

Estimate the range in cm in air at STP for electrons of energy (a) 50 keV, (b) 830 keV, (c) 100 MeV.

Problem 38 [Turner Prob. 6.19]

A positron emerges normally from a 4-mm thick palstic slab (ρ=1.19 g/cm^3) with an energy of 1.62 MeV. What was its energy when it entered the slab?

Problem 39 [Turner Prob. 6.21]

A cell culture is covered with a 1-cm sheel of lucite (ρ=1.19 g/cm^3). What thickness of lead (in cm) os needed on top of the lucite to prevent 10-MeV beta rays from reaching the culture? Use the approximative empirical formulas relating range R(g/cm^2) to electron kinetic energy T(MeV):

T(MeV):	Lucite:	R=0.334 T$^{1.48}$	$0 \leq$ T ≤ 4
	Lead:	R=0.426 T$^{1.14}$	$0.1 \leq$ T ≤ 10

What advantage would be gained if the positions of the lucite and the lead were swapped, so that the lucite was on top?

Problem 40 [Turner Prob. 7.1]

A 4-MeV proton in water produces a delta ray with energy 0.1 Q_{max}. How large is the range of this delta ray compared with the range of the proton?

Problem 41 [Turner Prob. 7.2]

How does the maximum energy of a delta ray that can be produced by a 3-MeV alpha particle compare with that from a 3-MeV proton?

Problem 42 [Turner Prob. 7.16]

The count rate from a collimated, monoenergetic alpha particle beam is measured at different separations x in air. From the data given in the following table, determine:

X(cm)	counts per minute
1.0	380
2.0	374
2.5	379
2.6	381
2.7	375
2.8	365
2.9	308
3.0	243
3.1	181
3.2	98
3.3	10
3.4	0

(a) The mean range

(b) The extrapolated range

Problem 43 **[Juin 2010]**

Calculate the average energy and intensity of the following beams as they pass through a 1 mm thick lead sheet.

(a) Protons 60 MeV

(b) Neutrons 60 MeV

(c) Photons 60 MeV

Consider in all cases that the starting intensity is 10^6 part/cm^2.

dE/dx (60 MeV) = 5.09 MeV cm^2/g
$\lambda_{\mathrm{Pb}} = 8.41\ 10^{-2}$ cm^2/g
$\Sigma_{\mathrm{Pb}}(60 \text{ MeV}) = 7$ cm^{-1}
$\rho_{\mathrm{Pb}} = 9.747$ g/cm^{-3}

Problem 44 **[June 2011]**

(a) Calculate analytically the stopping power of 5 MeV α in air.

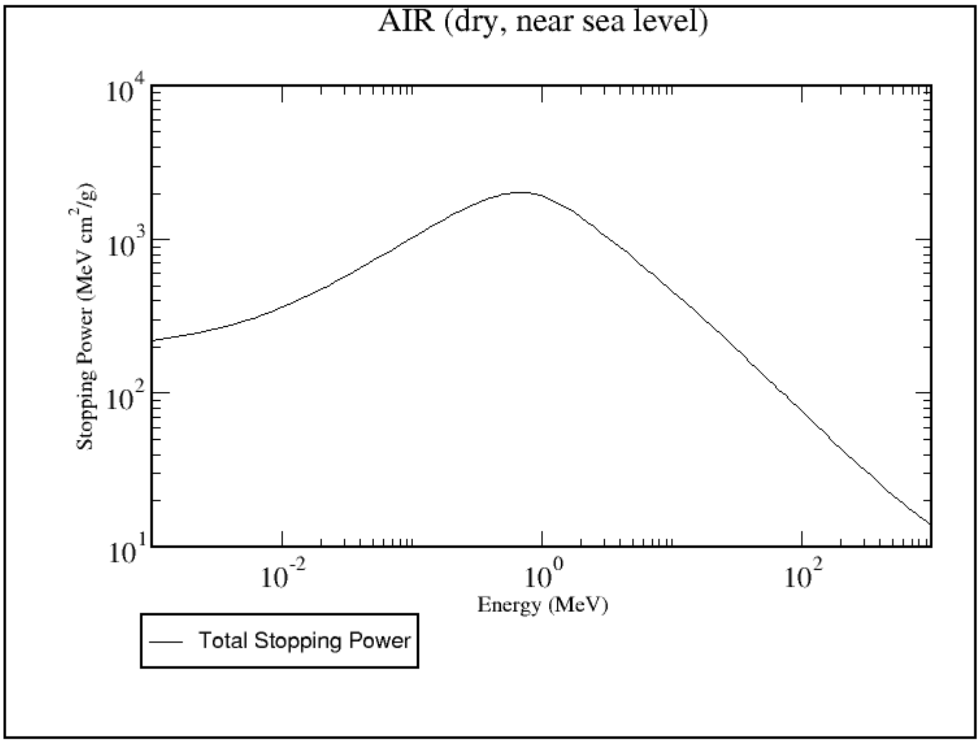
Hints:

- The answer(=value) is found in the graph from the *astar* software. In view of this graph, take into account in your calculation only those terms of the Bethe-Bloch expression that are relevant for the energy under consideration.
- Remember that $T_{max} \simeq 2m_ec^2\beta^2\gamma^2$ if $2\gamma m_e/M << 1$. Using this approximation the Bethe-Bloch formula simplifies.

(b) Calculate the range of the 5 MeV α particles in air and in a tissue

Data:

- Consider air composed of 80
- $\rho_{air} = 1.29 times 10^{-3}$ gr/cm^3, A_{air}=14.6
- $\rho_{tissue} = 1$ gr/cm^3, A_{tissue}=9



Problem 45 **[June 2012]**

A ^{3}He detector is used for neutron detection. Calculate the macroscopic cross section for 5 MeV neutrons ($sigma$=2400.065 mbarn) if

a) The pressure is 1 atm

b) The pressure is 10 atm

Consider in both cases that the operating temperature is 27^{o}C.

Problem 46 [June 2012]

The energy loss ($-\frac{dE}{dx}$) of a 10 MeV alpha(Z=2) in air is 463.7 MeV cm^2/g. What is the energy loss in MeV/cm:

a) of a proton (Z=1) of 10 MeV

b) of a ^{16}O nucleus (Z=8) also of 10 MeV

Consider that $M_{alpha} \simeq 4m_p$, $M_{^{16}O} \simeq 16m_p$ and rho_{air}=1.20479 × 10^{-3} g/cm^3

Data: Stopping power of alphas according to ASTAR

Energie (MeV)	Stp. Pow. (MeV cm^2/g)
1	1924
2	1383
3	1072
4	886.5
10	463.7
20	274.8
40	159.3
100	76.18

Problem 47 $\frac{dE}{dx}$ Scaling Law [January 2017]

The following table gives the energy loss $^{40}_{18}$Ar in silicon. What's the $\frac{dE}{dx}$ of a 700 MeV $^{58}_{28}$Ni nuclei in silicon?

Ion Energy	dE/dx Elec.	dE/dx Nuclear
350.00 MeV	1.049E+01	6.210E-03
375.00 MeV	1.010E+01	5.843E-03
400.00 MeV	9.735E+00	5.519E-03
450.00 MeV	9.087E+00	4.972E-03
500.00 MeV	8.525E+00	4.529E-03
550.00 MeV	8.032E+00	4.161E-03
600.00 MeV	7.596E+00	3.851E-03
650.00 MeV	7.208E+00	3.586E-03
700.00 MeV	6.861E+00	3.357E-03
800.00 MeV	6.266E+00	2.980E-03
900.00 MeV	5.778E+00	2.682E-03

Problem 48 X-rays mean free path [September 2017]

Estimate the mean free path of 150 keV x-ray photons traveling in ordinary water kept under normal atmospheric conditions. The total mass absorption coefficients of hydrogen and oxygen are 0.2651 cm^2/gr and 0.1361 cm^2/gr respectively

Problem 49 Landau fluctuations [January 2018]

A beam of 10 GeV proton passes through a thick silicon detector.

a) What's the mean energy loss if the thickness of the silicon sensor is:

 a.1) 100 μm

 a.2) 300 μm

 a.3) 500 μm

b) If we take into account the straggling, What's the most probable value and the width of the Landau distribution for:

 b.1) 100 μm

 b.2) 300 μm

 b.3) 500 μm

Problem 50 Range of high-energy particles [January 2018]

The mean stopping power for high-energy muons (or other heavy charged particles1) in a material can be described by,

$$\left\langle -\frac{dE}{dx} \right\rangle = a(E) + b(E)E$$

where E is the total energy, $a(E)$ is the electronic stopping power, that can be approximated with:

$$a(E) = 1.888 + 0.0768 \ln \frac{T_{max}}{m_\mu} \text{MeV cm}^2/\text{g}$$

and $b(E)$ is due to radiative processes: bremsstrahlung, pair production, and photonuclear interactions:

$$b(E) = b_{brem} + b_{pair} + b_{nucl}$$

This notation is convenient because a(E) and b(E) are slowly varying functions of E at the high energies where radiative contributions are important.

At 100 GeV, the value of b is

Fe	$5.6619 \times 10^{-6}\ \mathrm{cm^2/g}$
Rock	$3.0275 \times 10^{-6}\ \mathrm{cm^2/g}$

a) What's the value of the critical energy for muons in terms of a and b?

b) What's the range of in the CSDA approximation?

In both cases, compute the values for the case of Fe and Rock. Reminder:

$$T_{max} \simeq E$$
$$\gamma\beta \simeq \frac{E}{m}$$
$$m_e = 0.511\ \mathrm{MeV/c^2}$$
$$m_\mu = 105.658\ \mathrm{MeV/c^2}$$

Problem 51 Proton beam [January 2022]

Consider a 60 MeV proton beam provided by a cyclotron. At the exit of the cyclotron the beam has a gaussian shape with a width $\sigma_b = 1$ cm. After passing through a 100 μm diffusion sheet, the beam shape continues to be gaussian with a width $\sigma_{d1} = 2$ cm.

a) What will be the width of the beam, σ_{d2}, if the diffusion sheet would be of the same material but with a thickness of 200μm.

b) Does the ratio $\frac{\sigma_{d2}}{\sigma_{d1}}$ depend on the material of the diffusion sheet? Justify your answer.

c) Does the value of σ_{d1} depend on the material? Justify your answer.

Problem 52 Photon interaction [January 2022]

A beam of 1.75 MeV photons hits a 25mm-thick NaI crystal ($\rho_{NaI} = 3.667\mathrm{gr/cm^3}$):

a) What fraction of these photons have at least one interaction in the crystal?

b) What is the average distance traveled before the first interaction?

c) What fraction of the interactions is due to the photoelectric absorption?

The XCOM output providing the attenuation coefficient for 1.75 MeV gammas in NaI is:

Edge	(required) Photon Energy	Scattering		Photoelectric Absorption	Pair Production		Total Attenuation	
		Coherent	Incoherent		In Nuclear Field	In Electron Field	With Coherent Scattering	Without Coherent Scattering
	MeV	cm²/g	cm²/g	cm²/g	cm²/g	cm²/g	cm²/g	cm²/g
	1.750E+00	3.894E-04	4.055E-02	1.223E-03	1.606E-03	0.000E+00	4.376E-02	4.338E-02