DEVELOPMENT OF ELECTROMAGNETIC CASCADES IN THE ATMOSPHERE INCLUDING THE LANDAU-POMERANCHUK-MIGDAL EFFECT

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ABSTRACT

Numerical solutions have been obtained for the one-dimensional atmospheric electromagnetic cascade diffusion equations, including the LPM and screening effects. Spectra produced by primary gamma rays of various energies are given at a number of depths in the atmosphere.

1. Introduction. As the first step in a program to calculate the muon content of gamma-ray-induced atmospheric showers (1), we have carried out numerical solutions of the 1-dimensional electromagnetic cascade diffusion equations (2).

We have attempted to carry out a calculation with a minimum of approximation. The Landau-Pomeranchuk-Migdal (LPM) effect (3,4) on pair-production and bremsstrahlung cross sections has been included. The LPM cross sections were calculated using the formalism of Bowen et al. (5). Atmospheric densities were taken from the U. S. Standard Atmosphere. Constant collisional energy loss was included. Lastly, the effects of incomplete screening (6) were included.

The diffusion equations were integrated using the Runge-Kutta method. An initial condition of a single gamma ray vertically incident on the atmosphere was used. Electron and photon spectra down to 10 MeV were found throughout the atmosphere. Solutions have been obtained for incident gamma ray energies ranging from 10^{14} to 10^{19} eV. As a check, the LPM and incomplete screening effects can be removed, yielding the classical complete screening cross sections. In this case, the solutions obtained agree with Approximation B.

Figure 1 shows the atmospheric development of the integral electron spectra above 10 MeV for 6 incident gamma ray energies. Generally, the effects of the LPM cross sections on the integral spectrum are most pronounced at shallow atmospheric depths. For a 10^{19} eV incident gamma, at 550 g/cm^2 the ratio of the Approximation B integral spectrum (not shown here) above 10 MeV to the integral spectrum of Figure 1 is 1.56. At 1034 g/cm^2, the same ratio is 0.95.

Figures 2 and 3 show the differential electron spectra at 550, 700, 800, 900, and 1034 g/cm^2 for incident 10^{14} and 10^{16} eV gammas, respectively. While there are differences between this spectra and the corresponding Approximation B spectra at the 15 percent level, only above 10^{18} eV do the differential electron and photon spectra sharply and progressively deviate from the Approximation B spectra. Figure 4a shows the differential electron spectra induced by a 10^{19} eV gamma,

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again at the same 5 atmospheric depths as the previous figures. Figure 4b, plotted to the same scale, shows the Approximation B spectra.

References

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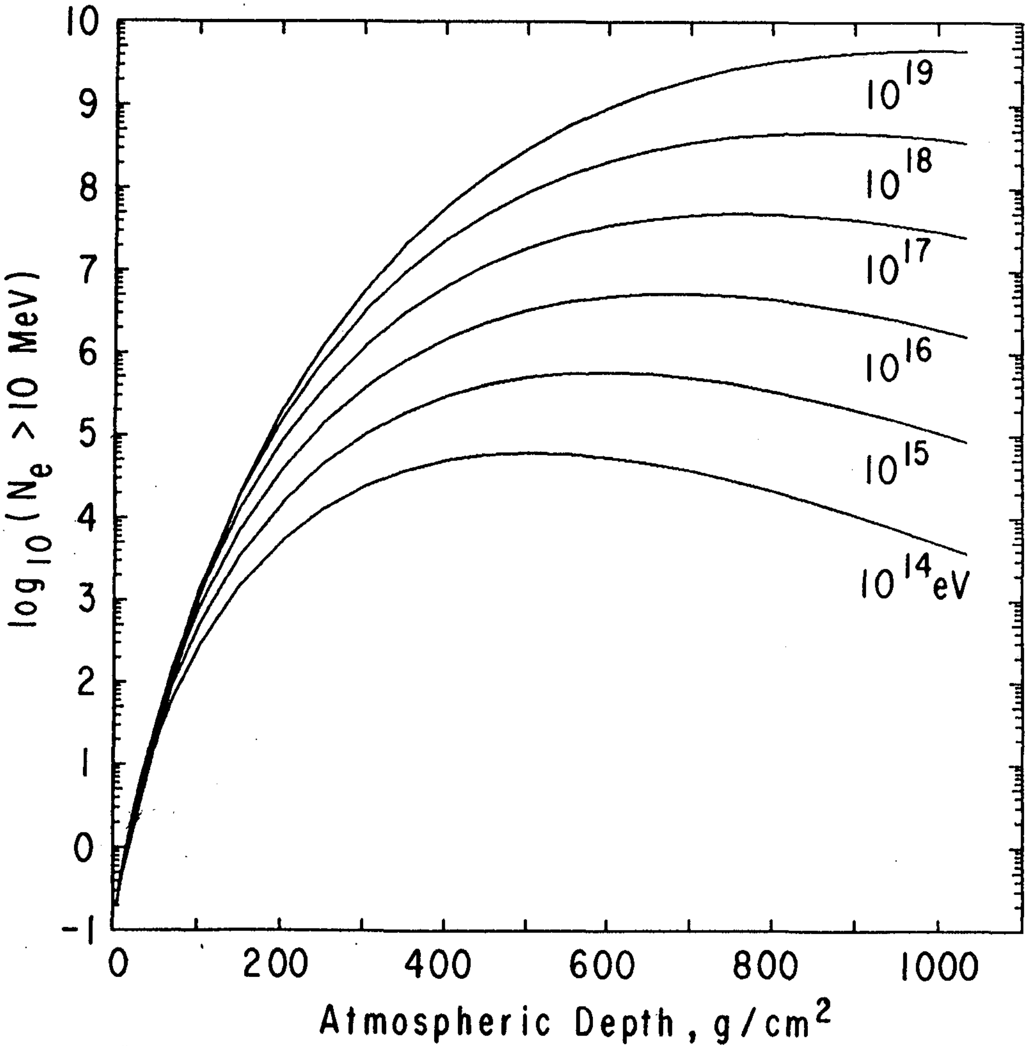
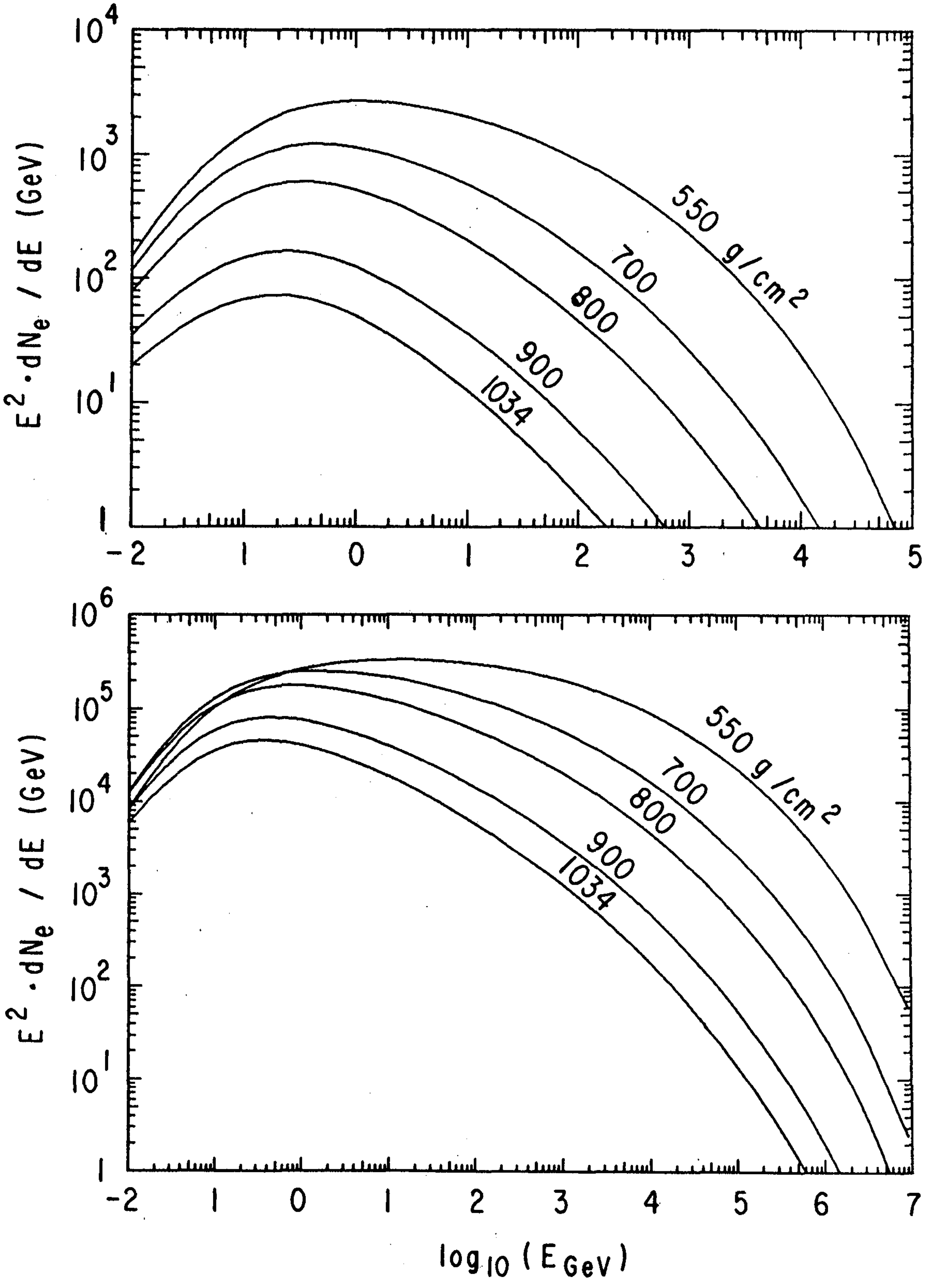


Figure 1.



Figures 2 (above) and 3 (below) for 10^{14} and 10^{16} eV, respectively

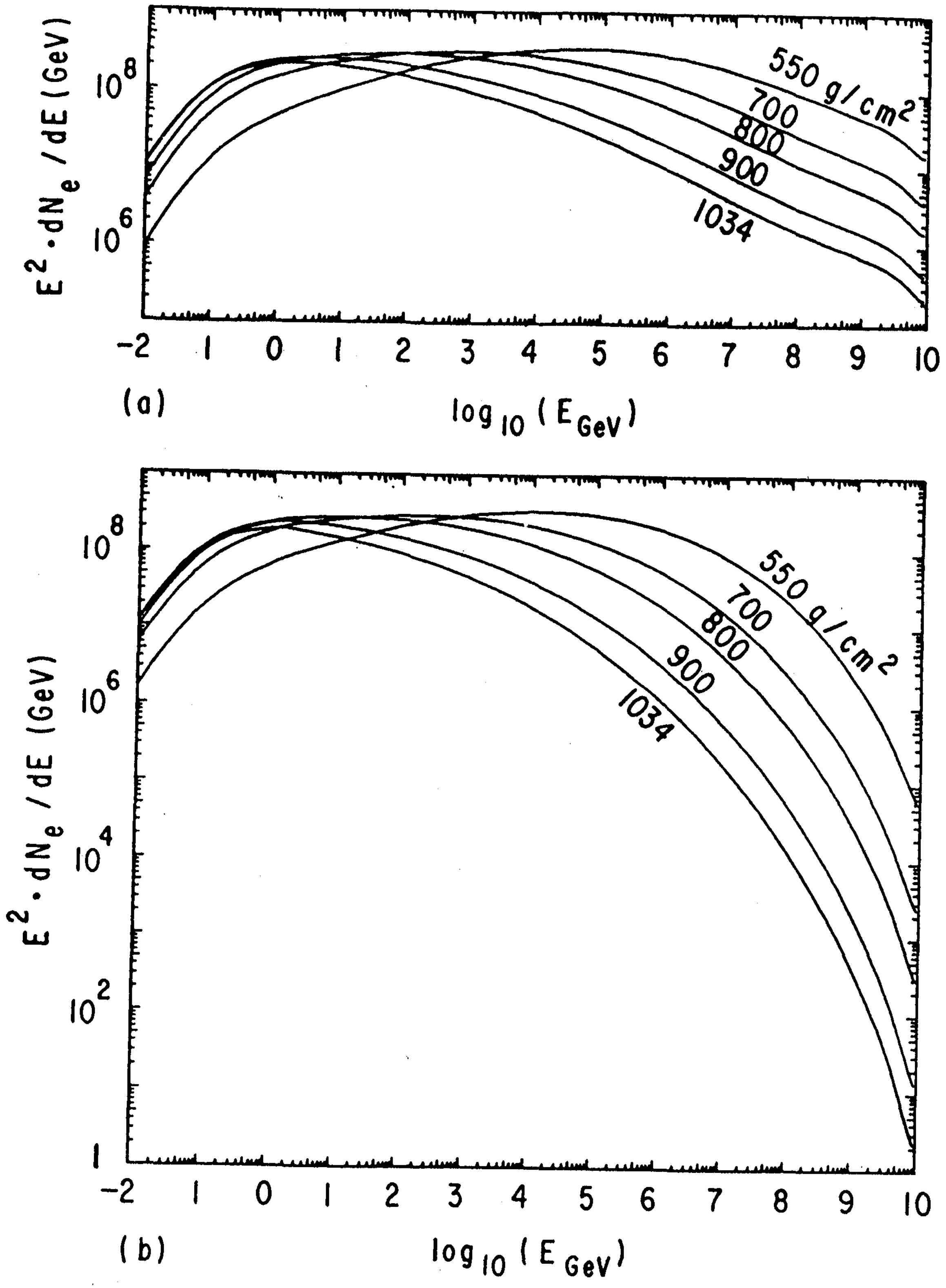

(a)
$E^2 \cdot dN_e/dE$ (GeV)
10^8
10^6
550 g/cm²
700
800
900
1034
−2
1
0
1
2
3
4
5
6
7
8
9
10
$\log_{10}(E_{GeV})$
(b)
$E^2 \cdot dN_e/dE$ (GeV)
10^8
10^6
10^4
10^2
1
550 g/cm²
700
800
900
1034
−2
1
0
1
2
3
4
5
6
7
8
9
10
$\log_{10}(E_{GeV})$

Figure 4