is independent of A, and this density is approximately 10^{14} times normal matter density and expresses the highly packed density of nucleus.

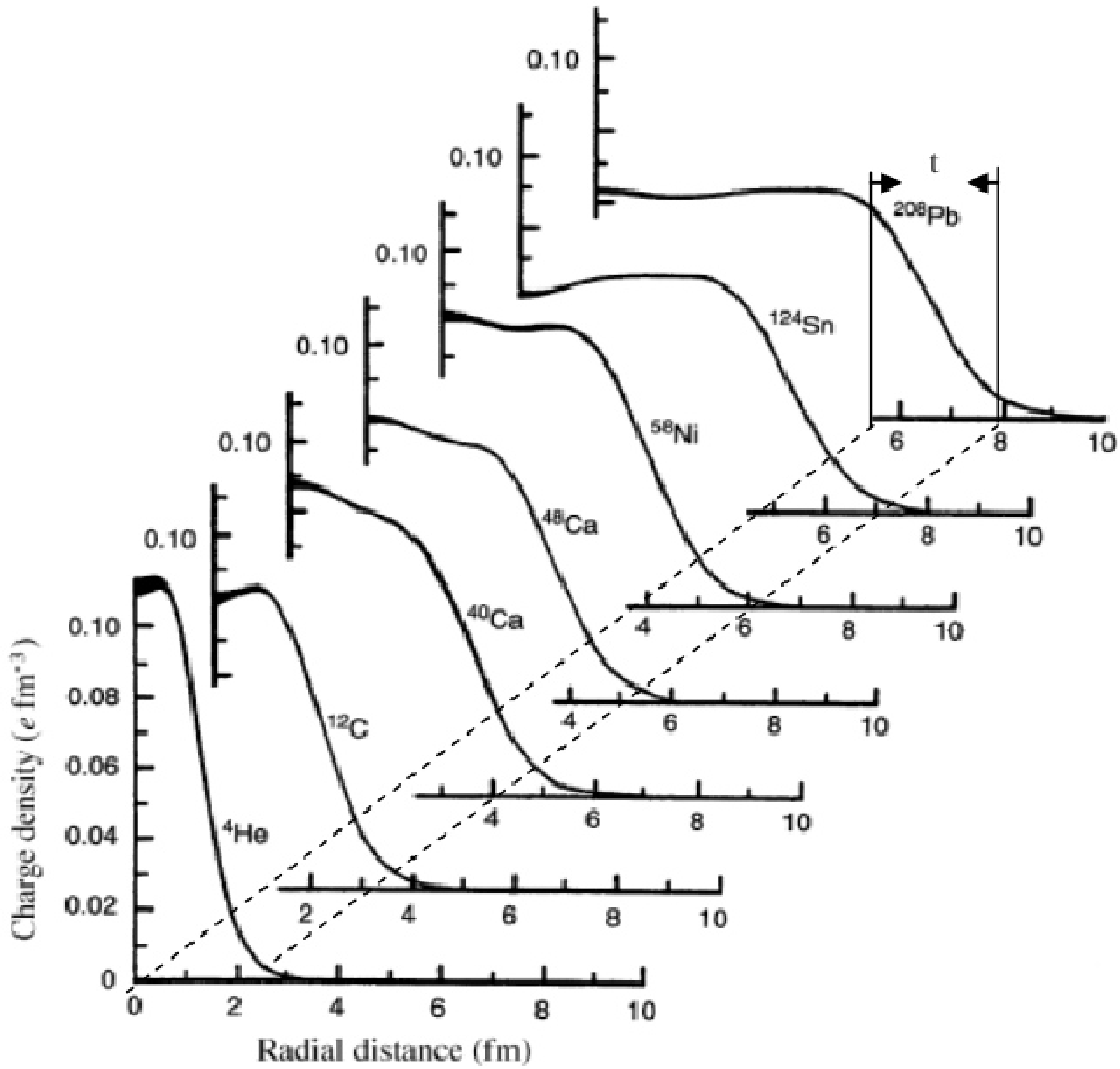

Figure 1.6. Radial charge distributions ρ_{ch} of various nuclei.

1.9. Forces in the Nucleus

In the Bohr's model of the atom, the nucleus consists of positively charged protons and electrically neutral neutrons. Since both protons and neutrons exist in the nucleus, they both referred to as nucleons. One problem that the Bohr's model of the atom faced was accounting for an attractive force to overcome the repulsive force between protons inside the nucleus.

The two classical forces present in the nucleus are (1) electrostatic forces between charged particles and (2) gravitational forces between any two objects that have mass. It is possible to calculate the magnitude of the gravitational force and electrostatic force based upon principles from classical physics. However, to bind the nucleus together, there must be a strong attractive force of totally different kind, strong enough to overcome the repulsive force of the positively charged nuclear protons and to bind both protons and neutrons into this tiny volume.

1.9.1. Gravitational force

Newton stated that the *gravitational force* between two bodies is directly proportional to the masses of the two bodies and inversely proportional to the square of the distance between the bodies. This relationship is shown in the equation below:

$$F_g = \frac{G m_1 m_2}{r^2} \qquad 1.34$$

where:

F_g = gravitational force (Newton)
m_1 = mass of first body (kilogram)
m_2 = mass of second body (kilogram)
G = gravitational constant (6.67×10^{-11} N-m^2/kg^2)
r = distance between particles (meter)

The equation illustrates that the larger the masses of the objects are or the smaller the distance between the objects is, the greater the gravitational force is. Therefore, even though the masses of nucleons are very small, the fact that the distance between nucleons is extremely short may make the gravitational force significant. It is necessary to calculate the value for the gravitational force and compare it to the value for other forces to determine the significance of the gravitational force in the nucleus. The gravitational force between two protons that are separated by a distance of 10^{-20} meters is about 10^{-24} Newtons.

1.9.2. Electrostatic force

Coulomb's Law can be used to calculate the force between two protons. The *electrostatic force* is directly proportional to the electrical charges of the two particles and inversely proportional to the square of the distance between the particles. Coulomb's Law is stated in terms of the following equation.

$$F_e = \frac{KQ_1Q_2}{r^2} \qquad 1.35$$

where:

F_e = electrostatic force (Newton)
$K = 1/4\pi\varepsilon_0$, electrostatic constant (9.0×10^9 N-m^2/C^2)
Q_1 = charge of first particle (coulomb)
Q_2 = charge of second particle (coulomb)
r = distance between particles (meter)

Using this equation, the electrostatic force between two protons that are separated by a distance of 10^{-20} meters is about 10^{12} Newtons. Comparing this result with the calculation of the gravitational force, (10^{-24} Newton) shows that the gravitational force is so small that one can neglect it.

1.9.3. Nuclear force

If only the electrostatic and gravitational forces existed in the nucleus, it would be impossible to have stable nuclei composed of protons and neutrons. The gravitational forces are much too small to hold the nucleons together compared to the electrostatic forces repelling the protons. Since stable atoms of neutrons and protons do exist in nature, there must be other attractive force acting within the nucleus; this force is called the nuclear force.

The *nuclear force* is a strong attractive force that is independent of charge. It acts only between pairs of neutrons, pairs of protons, or a neutron and a proton. The nuclear force has a very short range; it acts only over distances approximately equal to the diameter of the nucleus (10^{-15} m), even less. The attractive nuclear force between all nucleons drops off with distance much faster than the repulsive electrostatic force does between protons. As will be seen in the next section, the nuclear force can be divided into three families of interactions due to a strong force that binds quarks together to form neutrons and protons.

In stable atoms, the attractive and repulsive forces in the nucleus are balanced. If the forces do not balance, the atom cannot be stable, and the nucleus will emit radiation in an attempt to achieve a more stable configuration. Table 1.3 summarizes the behavior of each force.