1-Introduction

1.1 Why Study Physics

Perhaps your reason for studying physics can be quickly summed up as **"Because it is required for my major!"**. Physics is the science on which all other natural and engineering sciences are built. All modern technological advances-from laser surgery to television, from computers to refrigerators, from cars to airplanes trace back directly to basic physics. A good grasp of essential physics concepts gives you a solid foundation on which to construct advanced knowledge in all sciences. For example, the conservation laws and symmetry principles of physics also hold true for all scientific phenomena and many aspects of everyday life. The study of physics will help you grasp the scales of **distance, mass, and time**, from the smallest constituents inside the nuclei of atoms to the galaxies that make up our universe.

All natural systems follow the same basic laws of physics, providing a unifying concept for understanding how we fit into the overall scheme of the universe. Physics is intimately connected with **mathematics** because it brings to life the abstract concepts used in **trigonometry, algebra, and calculus**. **The analytical thinking and general techniques for problem solving that you learn here will remain useful for the rest of your life.**

1.2 SI Unit Systems:

In high school, you may have been introduced to the international system of units and compared it to the British system of units in common use in the United States. You may have driven on a freeway on which the distances are posted both in ***miles and in kilometers*** or purchased food where the price was quoted per **lb and per kg**. The international system of units is often abbreviated as SI. Sometimes the units in this system are called ***metric units***. The **SI unit system** is the standard used for scientific work around the world. The base units for the SI system are given in Table 1.1. The first letters of the first four base units provide another commonly used name for the SI system: the MKSA system. The current definitions of these base units are as follows:

■ 1 meter (m) is the distance that a light beam in vacuum travels in 1/299,792,458 of a second. Originally, the meter was related to the size of the Earth.

■ 1 kilogram (kg) is defined as the mass of the international prototype of the kilogram. Tis prototype, is kept just outside Paris, France, under carefully controlled environmental conditions.

■ 1 second (s) is the time interval during which 9,192,631,770 oscillations of the electromagnetic wave that corresponds to the transition between two specific states of the cesium-133 atom. Until 1967, the standard for the second was

1/86,400 of a mean solar day. However, the atomic definition is more precise and more reliably reproducible.

Table 1.1 Unit Names and Abbreviations for the Base Units of the SI System of Units

Unit	Abbreviation	Base Unit for
meter	m	length
kilogram	kg	mass
second	s	time
ampere	A	current
kelvin	K	temperature
mole	mol	amount of a substance
candela	cd	luminous intensity

Units for all other physical quantities can be derived from the seven base units of Table 1.1. The unit for area, for example, is m2. The units for volume and mass density are m3 and kg/m3, respectively. The units for velocity and acceleration are m/s and m/s2, respectively. Some derived units were used so often that it became convenient to give them their own names and symbols. Often the name is that of a famous physicist. Table 1.2 lists the 20 derived SI units with special names. In the two rightmost columns of the table, the named unit is listed in terms of other named units and then in terms of SI base units. Also included in this table are the radian and steradian, the dimensionless units of angle and solid angle, respectively.

You can obtain SI-recognized multiples of the base units and derived units by multiplying them by various factors of 10. These factors have universally accepted letter abbreviations that are used as prefxes, shown in Table 1.3. The use of standard prefxes (factors of 10) makes it easy to determine, for example, how many centimeters (cm) are in a kilometer (km):

$$1\ km = 10^3 m = 10^3 m.(10^2 cm/m) = 10^5 cm$$

Table 1.2 Common SI Derived Units

Derived or Dimensionless Unit	Name	Symbol	Equivalent	Expressions
Absorbed dose	gray	Gy	J/kg	m2 s^{-2}
Activity	becquerel	Bq	—	s^{-1}
Angle	radian	rad	—	—
Capacitance	farad	F	C/V	$m^{-2}\ kg^{-1}\ s^4\ A^2$
Catalytic activity	katal	kat	—	s^{-1} mol
Dose equivalent	sievert	Sv	J/kg	$m^2\ s^{-2}$
Electric charge	coulomb	C	—	s A
Electric conductance	siemens	S	A/V	$m^{-2}\ kg^{-1}\ s^3\ A^2$
Electric potential	volt	V	W/A	$m^2\ kg\ s^{-3}\ A^{-1}$
Electric resistance	ohm	Ω	V/A	$m^2\ kg\ s^{-3}\ A^{-2}$
Energy	joule	J	N m	$m^2\ kg\ s^{-2}$
Force	newton	N	—	$m\ kg\ s^{-2}$
Frequency	hertz	Hz	—	s^{-1}
Illuminance	lux	lx	lm/m^2	m^{-2} cd
Inductance	henry	H	Wb/A	$m^2\ kg\ s^{-2}\ A^{-2}$
Luminous flux	lumen	lm	cd sr	cd
Magnetic flux	weber	Wb	V s	$m^2\ kg\ s^{-2}\ A^{-1}$
Magnetic field	tesla	T	Wb/m^2	$kg\ s^{-2}\ A^{-1}$
Power	watt	W	J/s	$m^2\ kg\ s^{-3}$
Pressure	pascal	Pa	N/m^2	$m^{-1}\ kg\ s^{-2}$
Solid angle	steradian	sr	—	—
Temperature	degree Celsius	°C	—	K

Table 1.3 SI Standard Prefixes

Factor	Prefix	Symbol	Factor	Prefix	Symbol
10^{24}	yotta-	Y	10^{-24}	yocto-	y
10^{21}	zetta-	Z	10^{-21}	zepto-	z
10^{18}	exa-	E	10^{-18}	atto-	a
10^{15}	peta-	P	10^{-15}	femto-	f
10^{12}	tera-	T	10^{-12}	pico-	p
10^{9}	giga-	G	10^{-9}	nano-	n
10^{6}	mega-	M	10^{-6}	micro-	µ
10^{3}	kilo-	k	10^{-3}	milli-	m
10^{2}	hecto-	h	10^{-2}	centi-	c
10^{1}	deka-	da	10^{-1}	deci-	d

The use of powers of 10 is not completely consistent even within the SI system itself. The notable exception is in the time units, which are not factors of 10 times the base unit (second):

- 365 days form a year,
- a day has 24 hours,
- an hour contains 60 minutes, and
- a minute consists of 60 seconds.

1.3 Units of land area

The unit of land area used in countries that use the SI system is the **hectare**, defined as 10,000 m^2. In the United States, land area is given in **acres**; an acre is defined as 43,560 ft^2.

Example:

You just bought a plot of land with dimensions 2.00 km by 4.00 km. What is the area of your new purchase in hectares and acres?

Solution:

The area A is given by

$$A = \text{length} \cdot \text{width} = (2.00 \text{ km})(4.00 \text{ km}) = (2.00 \cdot 10^3 \text{ m})(4.00 \cdot 10^3 \text{ m})$$
$$A = 8.00 \text{ km}^2 = 8.00 \cdot 10^6 \text{ m}^2.$$

The area of this plot of land in hectares is then

$$A = 8.00 \cdot 10^6 \text{ m}^2 \frac{1 \text{ hectare}}{10{,}000 \text{ m}^2} = 8.00 \cdot 10^2 \text{ hectare} = 800. \text{ hectare.}$$

To find the area of the land in acres, we need the length and width in British units:

$$\text{length} = 2.00 \text{ km} \frac{1 \text{ mi}}{1.609 \text{ km}} = 1.24 \text{ mi} \frac{5{,}280 \text{ ft}}{1 \text{ mi}} = 6{,}563 \text{ ft}$$
$$\text{width} = 4.00 \text{ km} \frac{1 \text{ mi}}{1.609 \text{ km}} = 2.49 \text{ mi} \frac{5{,}280 \text{ ft}}{1 \text{ mi}} = 13{,}130 \text{ ft.}$$

The area is then

$$A = \text{length} \cdot \text{width} = (1.24 \text{ mi})(2.49 \text{ mi}) = (6{,}563 \text{ ft})(13{,}130 \text{ ft})$$
$$A = 3.09 \text{ mi}^2 = 8.61 \cdot 10^7 \text{ ft}^2.$$

In acres, this is

$$A = 8.61 \cdot 10^7 \text{ ft}^2 \frac{1 \text{ acre}}{43{,}560 \text{ ft}^2} = 1980 \text{ acres.}$$

1.4 The Scales of our World:

1.4.1 Length Scales:

Length is defined as the distance measurement between two points in space. Figure 1.4 shows some length scales for common objects and systems that span over 40 orders of magnitude.

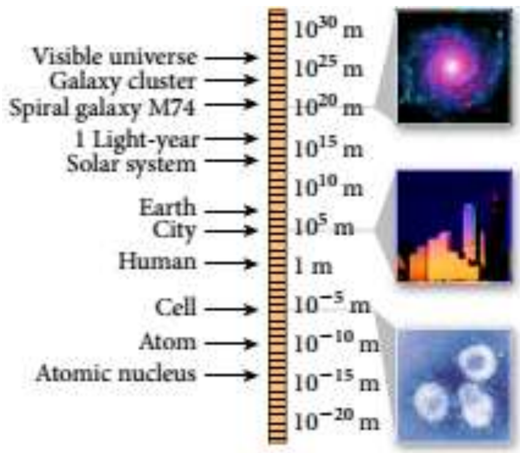

Figure 1.4 Range of length scales for physical systems. The pictures top to bottom are the Spiral Galaxy M 74, the Dallas skyline, and the SARS virus.

1.4.2 Mass Scales:

Mass is the amount of matter in an object. When you consider the range of masses of physical objects, you obtain an even more awesome span of orders of magnitude (Figure 1.5) than for lengths

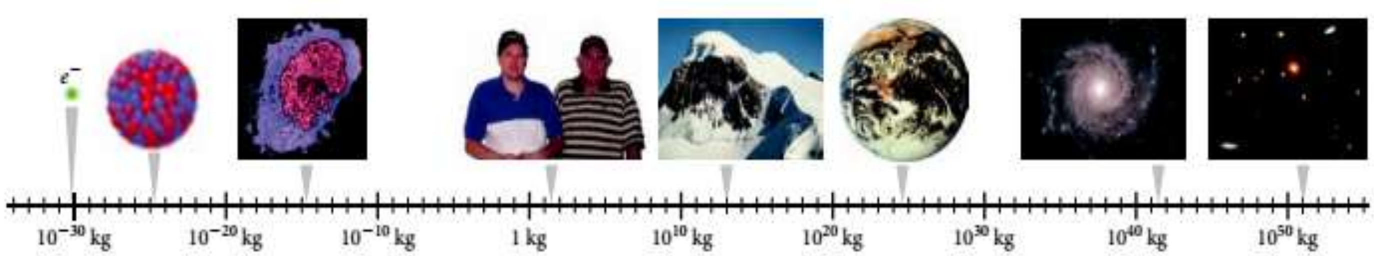

Figure 1.5 Range of mass scales for physical systems.

2- Electrostatics

In this chapter, we examine the properties of electric charge. A moving electric charge gives rise to a separate phenomenon, called *magnetism*, which is covered in later chapters. Here we look at charged objects that are **not moving**—hence the term ***electrostatics.***

All objects have charge, since charged particles make up atoms and molecules. We often don't notice the effects of electrical charge because most objects are electrically neutral. The forces that hold atoms together and that keep objects separate even when they're in contact, are all electric in nature.

2.1 Electric Charge

Let's look a little deeper into the cause of the electric sparks that you occasionally receive on a dry winter day if you walk across a carpet and then touch a metal doorknob.

Charging consists of the transfer of negatively charged particles, called **electrons,** from the atoms and molecules of the material of the carpet to the soles of your shoes. This charge can move relatively easily through your body, including your hands. The built-up electric charge discharges through the metal of the doorknob, creating a spark. The two types of electric charge found in nature are **positive**

charge and **negative charge.** Normally, objects around us do not seem to be charged; instead, they are electrically neutral. Neutral objects contain roughly equal numbers of positive and negative charges that largely cancel each other. Only when positive and negative charges are not balanced do we observe the effects of electric charge.

2.2 Law of Electric Charge:

The unit of electric charge is the **coulomb** (C), named after the French physicist Charles-Augustine de Coulomb (1736–1806). The coulomb is defined in terms of the SI unit for current, the ampere (A), named after another French physicist, André-Marie Ampère (1775–1836). Neither the ampere nor the coulomb can be derived in terms of the other SI units: meter, kilogram, and second. Instead, the ampere is another fundamental SI unit. For this reason, the SI system of units is sometimes called *MKSA (meter-kilogram-second-ampere) system.* The charge unit is defined as

$$\mathbf{1\ C = 1\ A\ s} \qquad \mathbf{(2.1)}$$

The definition of the ampere must wait until we discuss current in later chapters. However, we can define the magnitude of the coulomb by simply specifying the charge of a single electron:

$$q_e = -\,e \qquad (2.2)$$

where q_e is the charge and e has the (currently best accepted and experimentally measured) value

$$e = 1.602176487 \times 10^{-19}\ \text{C} \qquad (2.3)$$

We will use a value of 1.602 in this chapter, but you should keep in mind that equation 2.3 gives the full accuracy to which this charge has been measured.) The charge of the electron is an intrinsic property of the electron, just like its mass. The charge of the **proton,** another basic particle of atoms, is exactly the same magnitude as that of the electron, only the proton's charge is positive:

$$q_p = +e \qquad (2.4)$$

One coulomb is an extremely large unit of charge. We'll see later in this chapter just how big it is when we investigate the magnitude of the forces of charges on each other. Units of μC (microcoulombs, 10^{-6} C), nC (nanocoulombs, 10^{-9} C), and pC (picocoulombs, 10^{-12} C) are commonly used.

2.3 **Insulators, Conductors, Semiconductors, and Superconductors**

Materials that conduct electricity well are called **conductors.** Materials that do not conduct electricity are called **insulators.** (Of course, there are good and poor conductors and good and poor insulators, depending on the properties of the specific materials.)

The electronic structure of a material refers to the way in which electrons are bound to nuclei.

For **insulators**, no free movement of electrons occurs because the material has no loosely bound electrons that can escape from its atoms and thereby move freely throughout the material. Even when external charge is placed on an insulator, this external charge cannot move appreciably. Typical insulators are **glass, plastic, and cloth**.

On the other hand, materials that are **conductors** have an electronic structure that allows the free movement of some electrons. The positive charges of the atoms of a conducting material do not move, since they reside in the heavy nuclei. Typical solid conductors are metals. **Copper**, for example, is a very good conductor used in electrical wiring.

Fluids and organic tissue can also serve as conductors. **Pure distilled** water is not a very good conductor. However, dissolving common table **salt** (NaCl), for example, in water improves its conductivity tremendously, because the positively charged sodium ions **(Na+)** and negatively charged chlorine ions (Cl–) can move within the water to conduct electricity. In liquids, unlike solids, positive as well as negative charge carriers are mobile. Organic tissue is not a very good conductor, but it conducts electricity well enough to make large currents dangerous to us.

A class of materials called **Semiconductors** can change from being an insulator to being a conductor and back to an insulator again. The first widespread use of semiconductors was in transistors; modern computer chips perform the functions of millions of transistors. Computers and basically all modern consumer electronics products and devices (televisions, cameras, video game players, cell phones, etc.) would be impossible without semiconductors.

Semiconductors are of two kinds: ***intrinsic and extrinsic***. Examples of intrinsic semiconductors are chemically pure crystals of gallium arsenide, germanium, or, especially, silicon. Engineers produce extrinsic semiconductors by doping, which is the addition of minute amounts (typically 1 part in 10^6) of other materials that can act as **electron donors or electron receptors**.

Semiconductors doped with electron donors are called n-type (n stands for "negative charge"). If the doping substance acts as an electron receptor, the hole left behind by an electron that attaches to a receptor can also travel through the semiconductor and acts as an effective positive charge carrier. These semiconductors are consequently called p-type (p stand for "positive charge"). Thus, unlike normal solid conductors in which only negative charges move, semiconductors have movement of negative or positive charges (which are really electron holes that is, missing electrons).

Superconductors are materials that have zero resistance to the conduction of electricity, as opposed to normal conductors, which conduct electricity well but with some losses. Materials are superconducting only at very low temperatures. A typical superconductor is a niobium-titanium alloy that must be kept near the temperature of liquid helium (4.2 K) to retain its superconducting properties. During the last 20 years, new materials called *high-*T_c *superconductors* (T_c stands for "critical temperature," which is the maximum temperature that allows superconductivity) have been developed. These are superconducting at liquid-nitrogen temperature (77.3 K). Materials that are superconductors at room temperature (300 K) have not yet been found, but they would be extremely useful.

2.4 Electrostatic Force - Coulomb's Law

The law of electric charges is evidence of a force between any two charges at **rest**. Experiments show that for the electrostatic force exerted by a charge q_2 on a charge q_1, $\vec{F}_{2\to1}$, the force on q_1 points toward q_2 if the charges have opposite signs and away from q_2 if the charges have like signs (Figure 2.1). This force on one charge due to another charge always lies on a line between the two charges. **Coulomb's Law** gives the magnitude of this force as

$$F = k\frac{|q_1 q_2|}{r^2} \qquad (2.1)$$

where q_1 and q_2 are electric charges, $r = |r_1 - r_2|$ is the distance between them, and **Coulomb's constant is**

$$k = 8.99 \cdot 10^9 \ \frac{\mathrm{N\,m}^2}{\mathrm{C}^2} \qquad (2.2)$$

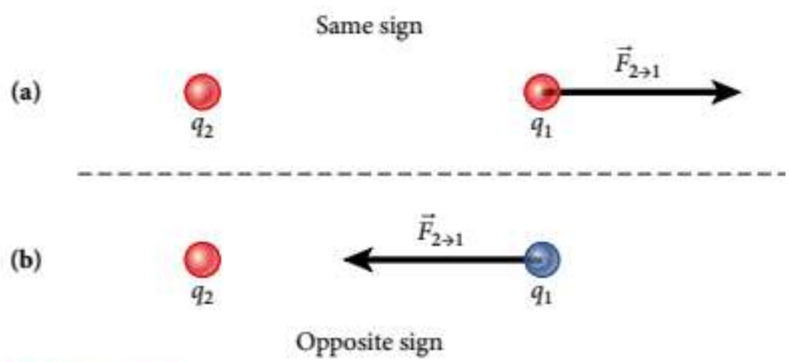

FIGURE 2 .1 The force exerted by charge 2 on charge 1: (a) two charges with the same sign; (b) two charges with opposite signs.

The relationship between Coulomb's constant and another constant, ϵ_0, called the **electric permittivity of free space,** is

$$k = \frac{1}{4\pi\epsilon_0}. \qquad (2.3)$$

Consequently, the value of ϵ_0 is

$$\epsilon_0 = 8.85 \cdot 10^{-12} \ \frac{\mathrm{C}^2}{\mathrm{N\,m}^2}. \qquad (2.4)$$

An alternative way of writing equation 2.1is then

$$F = \frac{1}{4\pi\epsilon_0}\frac{|q_1 q_2|}{r^2}. \qquad (2.5)$$

Finally, Coulomb's Law for the force due to charge 2 on charge 1 can be written in vector form:

$$\vec{F}_{2\to 1} = -k\frac{q_1 q_2}{r^3}(\vec{r}_2 - \vec{r}_1) = -k\frac{q_1 q_2}{r^2}\hat{r}_{21} \qquad (2.5)$$

In this equation, $\hat{r}_{21}$ is a unit vector pointing from $q2$ to $q1$ (see Figure 2.2). The negative sign indicates that the force is repulsive if both charges are positive or both charges are negative. In that case, $\vec{F}_{2\to 1}$ points away from charge 2, as depicted in Figure 2.2 a. On the other hand, if one of the charges is positive and the other negative, then $\vec{F}_{2\to 1}$ points toward charge 2, as shown in Figure 2.2b.

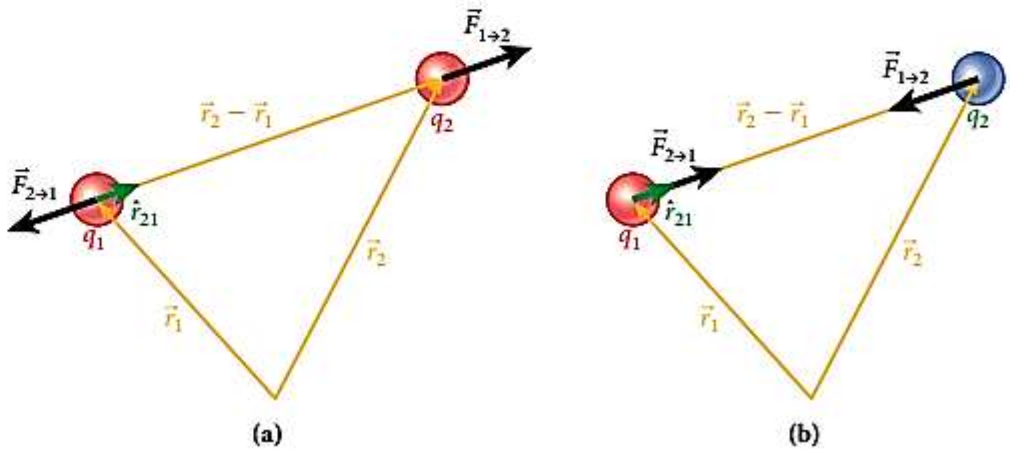

Figure 2.2 Electrostatic force vectors, which two charges exert on each other: (a) two charges of like sign; (b) two charges of opposite sign

2.5 Superposition Principle

So far in this chapter, we have been dealing with two charges. Now let's consider three point charges, q_1, q_2, and q_3, at positions x_1, x_2, and x_3, respectively, as shown in Figure 2.3 . The force exerted by charge 1 on charge 3, $\vec{F}_{1\to3}$, is given by

$$\vec{F}_{1\to3} = -\frac{kq_1q_3}{\left(x_3 - x_1\right)^2}\hat{x}.$$

The force exerted by charge 2 on charge 3 is

$$\vec{F}_{2\to3} = -\frac{kq_2q_3}{\left(x_3 - x_2\right)^2}\hat{x}.$$

The force that charge 1 exerts on charge 3 is not affected by the presence of charge 2. The force that charge 2 exerts on charge 3 is not affected by the presence of charge 1. In addition, the forces exerted by charge 1 and charge 2 on charge 3 add vectorially to produce a net force on charge 3:

$$\vec{F}_{\text{net}\to3} = \vec{F}_{1\to3} + \vec{F}_{2\to3}.$$

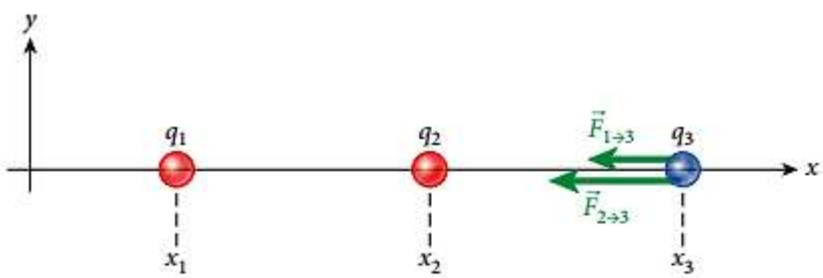

Figure 2.3 The forces exerted on charge 3 by charge 1 and charge 2.

Example 2.1:

What is the magnitude of the electrostatic force that the two protons inside the nucleus of a helium atom exert on each other? Where A distance of approximately $r = 2 \times 10^{-15}$ m separates the two protons.

Solution:

Using Coulomb's Law, we can find the force:

$$F = k\frac{|q_p q_p|}{r^2} = \left(8.99\cdot 10^9\ \frac{\text{N m}^2}{\text{C}^2}\right)\frac{\left(+1.6\cdot 10^{-19}\ \text{C}\right)\left(+1.6\cdot 10^{-19}\ \text{C}\right)}{\left(2\cdot 10^{-15}\ \text{m}\right)^2} = 58\ \text{N}.$$

Therefore, the two protons in the atomic nucleus of a helium atom are being pushed apart with a force of 58 N

Example 2.2:

What is the magnitude of the electrostatic force between a gold nucleus and an electron of the gold atom in an orbit with radius 4.88 · 10–12 m? Knowing that the charge of the gold nucleus is $q_N = +79e$. (Note that (e) is the charge of electron).

Solution:

The negatively charged electron and the positively charged gold nucleus attract each other with a force whose magnitude is;

$$F = k\frac{|q_e q_N|}{r^2},$$

where the charge of the electron is $q_e = -e$ and the charge of the gold nucleus is $q_N = +79e$.The force between the electron and the nucleus is then;

$$F = k\frac{|q_e q_N|}{r^2} = \left(8.99\cdot 10^9\ \frac{\text{N m}^2}{\text{C}^2}\right)\frac{\left(1.60\cdot 10^{-19}\ \text{C}\right)\left[(79)\left(1.60\cdot 10^{-19}\ \text{C}\right)\right]}{\left(4.88\cdot 10^{-12}\ \text{m}\right)^2} = 7.63\cdot 10^{-4}\ \text{N}.$$