Day 4: Physical Phenomena

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Introduction

This is the second writing on theoretical physics. I assume that you have completed the first readings for theoretical, mathematical, and computational physics, and that you have a little bit of experience with the topics I have already covered.

In this writing we will explore the idea of physical phenomena from a theoretical point of view. We will begin by exploring the particle theory of physical phenomena. Then, we will examine the concept of fields, explore more complicated theories of matter and end with a brief survey of applied physics.

Particle theory

Underlying idea of particles is the notion of abstraction. In studying a problem, we abstract away the size and shape of the object under study. This allows us to significantly simplify problems. Do we really believe that a car can move down the highway without regard to size and shape? No, not really; air will push against the car and the details of this pushing requires a study of the size and shape of the car and the composition and properties of the air. Thses are not the most significant effects, and they are not required to understand motion in general; but only to understand the detailed motion of the car in a specific situation. If our goal is to understand motion in all generality, we begin by the abstraction to the particle. This will be our guiding principle: Use particles only when we are able to consider motion without regard to size or shape.

Assume we have decided to make a particle-based model. We have decided that we do not need to consider the shape or size of the object under study. What do we need to do next? We choose the physical quantities we need for our study. The first kind of physical quantity we will consider is obtained by measurement. When something is measured, the first thing to do is determine a unit of measurement upon which all measurements will be based. We apply the unit, or a fraction thereof, a number of times. We then say there are that many units. For example, we measure the distance between two objects, or an object and an arbitrary location.

We might use meters as the unit, and then we count how many meters are between the object and the point. Such a quantity is called a *dimensional quantity*. Within this category of quantity, there are those upon which all others are based. They are called *fundamental quantities*, and those that are derived from them are called *derived quantities*. For a particle model, there are three absolutely fundamental dimensional quantities; *length* (defined as the distance between two points), *time* (this is an undefined term, but we understand this to be the ordering of events), and *mass* (another undefined term that signifies how much matter is present in an object). The units of length, time, and mass are determined by the system of measurement you are using.

System of Measuremen	Length	Time	Mass
English System	Foot (ft)	Second (sec)	Pound (lb)
SI System (Metric System)	Meter (m)	Second (sec)	Kilogram (kg)
CGS System	Centimeter (cm)	Second (sec)	Gram (gm)

Derived physical quantities require combining the fundamental quantities in some way. For example, area is length times length, or length^2. Here are some derived quantities.

System of Measuremen	Area	Volume	Density (Mass / Volume)
English System	Square Foot (ft^2)	Cubic Foot (ft^3)	$\frac{\text{Pound}}{\text{Cubic Foot}}$ ($\mathrm{lb\ ft}^{-3}$)
SI System (Metric System)	Square Meter (m^2)	Cubic Meter (m^3)	$\frac{\text{Kilogram}}{\text{Cubic Meter}}$ ($\mathrm{kg\ m}^{-3}$)
CGS System	Square Centimeter (cm^2)	Cubic Centimeter (cm^3)	$\frac{\text{Gram}}{\text{Cubic Centimeter}}$ ($\mathrm{gm\ cm}^{-3}$)

The second kind of physical quantity has no units and is called a *dimensionless quantity*. Any ratio of similar dimensional quantities will be dimensionless. For example, the ratio of masses of two objects is dimensionless.

$$\frac{10\,\mathrm{kg}}{20\,\mathrm{kg}} = \frac{10}{20}\frac{\mathrm{kg}}{\mathrm{kg}} = \frac{10}{20}\cdot 1 = \frac{1}{2}.$$

It is important to realize that mathematically, a measurement is a monomial. Recall that a monomial is a numerical coefficient multiplied by a symbolic variable. For example, $3\,x$ is a monomial where 3 is coefficient and x is the variable. In measurement the numerical part is the coefficient for the symbol of the unit. Thus, there is no structural difference between $3\,x$ and 3 ft.

Once we have established the physical quantities to be used, we need to identify the arguments of the theory being considered. Often these will be a list of formulas that we can use in coordination with the physical quantities. Here is a list of arguments that relate to the theory of particles in physics.

Argument	Name	Formula	Explanation
77	Position	$x = f(t)$	The position is a function of time t and is the distance, in units of length, from some arbitrary reference point to the particle in question.
78	Displacement	$\Delta x = x - x_0$	The displacement is the distance traveled by a particle. It can be calculated by subtracting a position x by the initial position x_0. This will have units of length.
79	Velocity	$v = \frac{dx}{dt}$	The velocity is the time rate of change of position of the particle, or put another way it is the time derivative of position. This will have units of length $\cdot$ time^{-1}.
80	Acceleration	$a = \frac{dv}{dt} = \frac{d^2x}{dt^2}$	The acceleration is the time rate of change of velocity of the particle, or the time derivative of velocity. This is also the second time derivative of position, and will have units of length $\cdot$ time^{-2}.
81	Velocity II	$v = \int_0^t a \, dt'$	The velocity of a particle can also be considered to be the time integral of the acceleration from initial time $t = 0$ to some later time t.
82	Position II	$x = \int_0^t v \, dt' = \int_0^t \int_0^t a \, dt' \, dt''$	The position of a particle can be thought of as being the time integral of velocity, or the second time integral of the acceleration, from some initial time $t = 0$ to some later time t.

Now that we have some arguments and quantities, it is time to choose a formulation of the theory. In very broad terms, there are three mathematical formulations for any kind of theory. The first is based upon our understanding of shape and distance, this is called the *geometric formulation*. The second is based upon an analysis using principles of calculus, this is called an *analytical formulation*. And the third is based on structural/logical analysis of the formulas being considered, this is called an *algebraic formulation*. For this writing, I choose take a specific geometric formulation that uses the notion of distance and direction called the *vector kinematical formulation*. A *vector* is a geometrical object that has both length and direction. Anything that has both direction and length can be represented by a vector. In this writing, vectors will be represented by a bold symbol, such as x. When writing a vector by hand, it is wise to put a half arrow over the top of the symbol, such as $\vec{x}$.

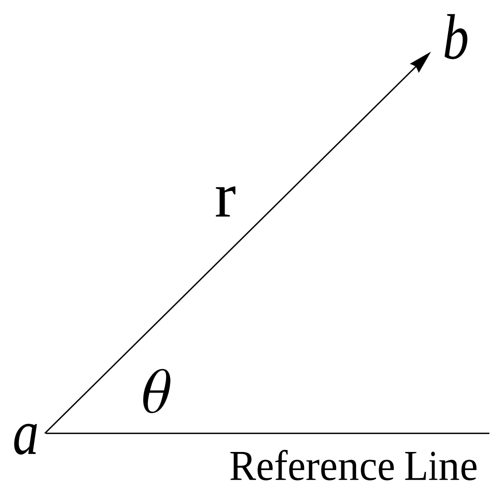

Figure 1. A Vector

In Figure 1, we can see a representation of a vector. We draw an arrow from the base of the vector, point *a*, to the head of the vector, point *b*. We label this vector as r. From the base we draw a reference line, which we will use to measure the angle of the vector θ. The length of the vector is denoted as $|\mathrm{r}|$, or just r. Here are some arguments based on the vector kinematical formulation.

Argument	Name	Formula	Explanation
83	Position Vector	$\mathrm{r} = (r(t), \theta(t))$	The position vector is a list of components, specifically the length of the postion vector, r, as a function of time, t, and the direction angle, θ, also as a function of time.
84	Displacement Vector	$\Delta \mathrm{r} = \mathrm{r} - \mathrm{r}_0$	The displacement vector is the difference of a given position vector subtracted by the initial position vector, see Figure 2.
85	Velocity Vector	$\mathrm{v} = \frac{d\mathrm{r}}{dt}$	The velocity vector is the time derivative of the position vector.
86	Acceleration	$\mathrm{a} = \frac{d\mathrm{v}}{dt} = \frac{d^2\mathrm{r}}{dt^2}$	The acceleration is the time derivative of the velocity vector. This is the second time derivative of the position vector.
87	Velocity Vector II	$\mathrm{v} = \int_0^t \mathrm{a}\, dt'$	The velocity vector of a particle can also be considered to be the time integral of the acceleration vector from initial time $t = 0$ to some later time t.
88	Position Vector II	$\mathrm{r} = \int_0^t \mathrm{v}\, dt' = \int_0^t \int_0^t \mathrm{a}\, dt'\, dt''$	The position vector of a particle can be thought of as being the time integral of velocity vector, or the second time integral of the acceleration vector from some initial time $t = 0$ to some later time t.

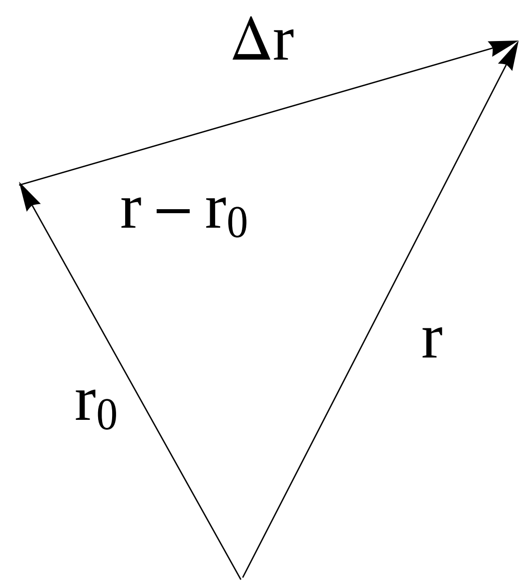

Figure 2. The Displacement Vector, shown as the difference of r - r_0.

We have some quantities and arguments to develop our theory with, and a formulation,. The next ingredient is an arena within which to study our phenomena. We have introduced the idea of a vector as a direction and a length. Now, we need a way to represent these ideas numerically. To do this we choose, as our arena, the Cartesian coordinate system. In three dimensions, all of the vectors will have a component in the x-direction, the y-direction, and the z-direction, as specified in Figure 3.

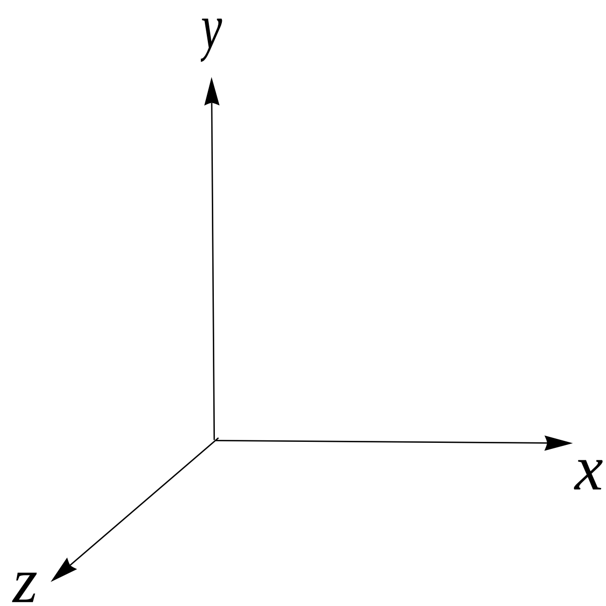

Figure 3. Cartesian coordinates.

The components of a vector, in Cartesian coordinates, are the distances from the origin to the head of the vector in each direction. In effect this distance is like the shadow cast by the vector along each coordinate axis. This gives us the following additional arguments.

Argument	Name	Formula	Explanation
89	Position Vector in a Cartesian System	$\mathrm{r} = (x(t),\ y(t), z(t))$	The components of the position vector is the distance from the origin to the head of the vector in each the x, y, and z directions.
90	Displacement Vector in a Cartesian System	$\Delta\,\mathrm{r} = (x - x_0, y - y_0, z - z_0)$	The components of the displacement vector are the distance intervals in each direction.
91	Velocity Vector in a Cartesian System	$\mathrm{v} = (x'(t),\ y'(t), z'(t))$	The velocity vector is the time derivative of the position vector.
92	Acceleration Vector in a Cartesian System	$\mathrm{a} = \left(v_x'(t), v_y'(t), v_z'(t) = (x''(t),\ y''(t), z''(t)\right)$	The acceleration vector is the time derivative of the velocity vector.
93	Velocity Vector II in a Cartesian System	$\mathrm{v} = \int_0^t \left(a_x, a_y, a_z\right) dt'$	The velocity vector can also be thought of as the time integral of the acceleration vector.
94	Position Vector II in a Cartesian System	$\mathrm{r} = \int_0^t \left(v_x, v_y, v_z\right) dt' = \int_0^t \int_0^t \left(a_x, a_y, a_z\right) dt'\, dt''$	The position vector can also be thought of as the time integral of the velocity vector, or the second time integral of the acceleration vector.

We are now ready to study the phenomena of particle physics. But what phenomena can we study? We know from arguments 88 and 93 that given a position vector whose components are functions of time, we can determine the velocity and acceleration vectors at any later time. We also know that given an acceleration vector whose components are functions of time, we can determine the velocity and position at any later time.

Let us assume that we have a falling body just above the surface of the Earth. We decide that the object is a height above the ground, so $z_0 = h$, and it is dropped at time $t = 0$, with no initial velocity, so $v_{z_0} = 0$, and under the acceleration due to the gravity of the Earth, so $a_{z_0} = -g$, where $g = 9.8\,\mathrm{m\,sec}^{-2}$. In our quest for simplicity, we will ignore air resistance and we will assume that h is small enough that the rotation of the Earth has no effect. This simplifies things greatly. It is important to note here that since the only acceleration present is straight down, that the non-z components of the acceleration will all be 0. We can write our acceleration vector as,

$$\mathrm{a} = (0, 0, -g).$$

Note that we have chosen a negative sign for the acceleration. This is because the acceleration points towards the ground. By argument 92, we can calculate the velocity,

$$\mathrm{v}(t) = \int \mathrm{a}\, dt$$

So,

$$\mathrm{v}(t) = \int (0, 0, -g)\, dt$$

By argument 66 from [1] we rewrite this,

$$\mathrm{v}_z(t) = -\int g\, dt.$$

By argument 67, from [1] we rewrite this,

$$\mathrm{v}_z(t) = c - g\,t. \tag{1}$$

We can find the constant of integration by setting $t = 0$. At this time the velocity is termed the initial velocity and given the symbol v_{z_0},

$$\mathrm{v}_{z_0} = c.$$

Substituting this result into (1) gives us,

$$\mathrm{v}_z(t) = \mathrm{v}_{z_0} - g\,t. \tag{2}$$

So, the velocity vector is now,

$$\mathrm{v}(t) = (0, 0, -g\,t). \tag{3}$$

By applying argument 94 along with the Fundamental Theorem of Calculus (argument 71 in [1]) we can calculate the position vector at any time.

$$\mathrm{r}(t) = \int (0, 0, -g\,t)\,dt$$

By applying similar arguments used in getting (1), we have,

$$\mathrm{r}_z(t) = c - \frac{1}{2} g\,t^2. \tag{4}$$

Once again we set $t = 0$, this time we have the initial position as the height, h.

$$h = c.$$

So we can substitute this into (4),

$$\mathrm{r}(t) = \left(0, 0, h - \frac{1}{2} g\,t^2\right). \tag{5}$$

Thus we can predict the motion of a particle. We can then verify these using *Mathematica*, as described in [2]. Begin by defining the acceleration.

```
a = {0, 0, -g}
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$\{0, 0, -g\}$

Then we define the velocity in general as,

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v[t] = ∫a ⅆt + v0
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$\{v_0, v_0, -g\,t + v_0\}$

in our situation this becomes, (using the substitution symbol /.),

```
v[t] /. v0 → 0
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$\{0, 0, -g\,t\}$

This confirms our result in (3). The position is then,

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r[t] = ∫v[t] ⅆt + {0, 0, h}
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$$\left\{t\,v_0,\ t\,v_0,\ h - \frac{g\,t^2}{2} + t\,v_0\right\}$$

and for our situation,

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r[t] /. v0 → 0
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$$\left\{0,\ 0,\ h - \frac{g\,t^2}{2}\right\}$$

which confirms our result in (5).

Field theory

One level of complication beyond the particle viewpoint is one where a property is expressed at every conceivable point within a region you are considering. This is how we defined a field in [3]. If we assume that there is a field, the central question is what effect, if any, does this field have on some sort of a particle within that field? Another question that arises is, "Given specific circumstances generating the field, what shape does it take?" Often a third question arises, but for the most part field theories are not capable of answering it. What is the mechanism that causes the field to come into being? At this point, we will consider the following fields: the temperature field, the gravitational field, and the electric field.

Here are some important physical quantities for the fields we will study.

Quantity	Symbol	SI Units	cgs units
Temperature	T	Kelvin	Kelvin
Charge	q	Coulomb (C)	Electrostatic Unit (esu)
Force	F	Newton (N) $= \text{kg m sec}^{-2}$	Dyne (dyn) $= \text{gm cm sec}^{-2}$

We also have two important physical constants, values that we assume never change.

Constant	Symbol	SI Units	cgs units
Newton' s Gravitational Constant	G	$6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2}$	$6.67 \times 10^{-8}\ \text{dyn cm}^2\ \text{gm}^{-2}$
The Coulomb Constant	k	$8.99 \times 10\ \text{N m}^2\ \text{C}^{-2}$	1

Here are the relevant physical arguments, along with necessary mathematical concepts.

Argument	Name	Formula	Explanation
95	Scalar Field	$\phi(x)$	This tells us that there is a value of the scalar ϕ at every point x in the region under study. If the space is the three dimensional Cartesian system used above, then we would write $\phi(x,\ y,\ z)$ and we would call ϕ a scalar function of more than one variable.
96	Dynamical Scalar Field	$\phi(x,\ t)$	A dynamical scalar field is one that changes with respect to the parameter t.
97	Partial Derivative	$\frac{\partial\phi(x,y,z)}{\partial x}$	A partial derivative is a derivative with respect to one variable where you hold all other variables as constants. It is the rate of change in a specific direction.
98	Nabla Operator	∇	This is the list of the partial derivatives with respect to the different directions in a given coordinate system. In the Cartesian system $\nabla = \left\{\frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z}\right\}$.
99	Product of a Scalar and a Vector	a b	This is just the product of a and each component of b.
100	Gradient	$\nabla\ \phi$	The product of ϕ and ∇. In Cartesian coordinates this is $\left\{\frac{\partial\phi}{\partial x}, \frac{\partial\phi}{\partial y}, \frac{\partial\phi}{\partial z}\right\}$. This turns a scalar field into a vector field.
101	Inner Product	r · s	This is also called the *dot product*, and it is the sum of the corresponding components of the vectors. In the case of Cartesian coordinates we have, r · s = $(r_x \cdot s_x) + (r_y \cdot s_y) + (r_z \cdot s_z)$.

Argument	Name	Formula	Explanation
102	Divergence	$\nabla \cdot \mathrm{r}$	The inner product of the Nabla operator and a vector. In Cartesian coordinates this is $\frac{\partial \mathrm{r}}{\partial x} + \frac{\partial r}{\partial y} + \frac{\partial r}{\partial z}$. The divergence converts a vector field into a scalar field.
103	Norm of a Vector	$[\![r]\!]$	This is the length of a vector. In Cartesian coordinates this is given by the Pythagorean theorem, $\sqrt{r_x{}^2 + r_y{}^2 + r_z{}^2}$.
104	Unit Vector	$\hat{\mathrm{r}} = \frac{\mathrm{r}}{[\![r]\!]}$	This is a vector of length 1 pointing in the same direction as r.
105	Basis Vectors	$\hat{\mathrm{e}}$	These are unit vectors along each coordinate axis. In the Cartesian system they are $\hat{\mathrm{e}}_x$, $\hat{\mathrm{e}}_y$, and $\hat{\mathrm{e}}_z$.
106	Definition of a Vector in terms of basis vectors	r	$\mathrm{r} = r_1\, \hat{\mathrm{e}}_1 + r_2\, \hat{\mathrm{e}}_2 + ... + r_n\, \hat{\mathrm{e}}_n$, where the first index represents the first coordinate axis. In the Cartesian system this is x , the second index is the second coordinate axis, and so on. Thus we have a product between some coefficients unique to the vector and the corresponding basis vectors. This can be generalized to $\sum_{i=1}^{n} r_i\, \hat{\mathrm{e}}_i$.
107	Einstein Summation Convention		When dealing with vector indices we assume that each pair of index symbols is summed over all possible values. For example, $r_i\, \hat{\mathrm{e}}_i = \sum_{i=1}^{n} r_i\, \hat{\mathrm{e}}_i = r_1\, \hat{\mathrm{e}}_1 + r_2\, \hat{\mathrm{e}}_2 + ... + r_n\, \hat{\mathrm{e}}_n$.

Argument	Name	Formula	Explanation
108	Vector Product	$\mathbf{r} \times \mathbf{s}$	Sometimes this is called the cross product. In the Cartesian system we define $\mathrm{r} = r_i\, \hat{\mathrm{e}}_i$ and $\mathrm{s} = s_i\, \hat{\mathrm{e}}_i$. Then the vector product is $\mathrm{r} \times \mathrm{s} = (r_2\, s_3 - r_3\, s_2)\, \hat{\mathrm{e}}_1 + (r_3\, s_1 - r_1\, s_3)\, \hat{\mathrm{e}}_2 + (r_1\, s_2 - r_2\, s_1)\, \hat{\mathrm{e}}_3$.
109	Curl	$\nabla \times \mathrm{s}$	This represents the circulation of the vector field. In the Cartesian system we have $\nabla \times \mathrm{s} = \left(\frac{\partial s_2}{\partial z} - \frac{\partial s_3}{\partial y}\right) \hat{\mathrm{e}}_1 + \left(\frac{\partial s_3}{\partial x} - \frac{\partial s_1}{\partial z}\right) \hat{\mathrm{e}}_2 + \left(\frac{\partial s_1}{\partial y} - \frac{\partial s_2}{\partial x}\right) \hat{\mathrm{e}}_3$.
110	Gravitational Force	$\mathrm{F} = \frac{-G\, m_1\, m_2}{r^2}$	This is Newton's law of universal gravitation. It states that the pull exerted by the gravitation between two masses is a constant times the two masses, and is inversely proportional to the square of the distances between them.
111	Electrostatic Force	$\mathrm{F} = \frac{k\, q_1\, q_2}{r^2}$	This is Coulomb's law of the force of electricity. It states that the pull, or push, exerted by the electricity between two charges is a constant times the two charges, and is inversely proportional to the square of the distances between them.
112	The Electric Field	$\mathrm{E} = \frac{k\, [\![q]\!]}{r^2}$	The strength of the electric field at every point. It is basically the Electrostatic force divided by one of the charges.
113	Vector Field	$\mathrm{F}(x,\ y,\ z)$	This tells us thar there is a value of the field F at every point $(x,\ y,\ z)$ in the region under study.

I will now demonstrate an analytical formulation of field theory, specifically that of the electric field. Here are some arguments for the analytical formulation of the theory of the electric field.

Argument	Name	Formula	Explanation
114	Electric Force	$F = q_2 \, E$	The electric force experienced by a hypothetical particle of charge q_2 is that charge times the electric field of the source of the field
115	The Electric Force Due to n charges.	$F = q \, k \, q_1 \, q_2 \ldots q_n \frac{(r-r_i)}{\llbracket r-r_i \rrbracket^3}$	This tells us that the force between a source and some charge is proportional to the inverse square of the distance between the charges and in a direct line connecting them.
116	The Electric Field Due to n charges.	$E = k \, q_1 \, q_2 \ldots q_n \frac{(r-r_i)}{\llbracket r-r_i \rrbracket^3}$	This tells us that the force between a source and a collection of charges is proportional to the product of the charges and is also inversely proportional to the square of the distance between the charges and in a direct line connecting them.

From these arguments we can calculate the forces and fields produced by collections of masses and charges. Assume that we have charges of 1 C each located at three points, say $(1, 1, 1)$, $(-1, -1, 0)$, and $(2, 0, 1)$. What is the field produced? Using argument 116, we have,

$$E = k \sum_{i=1}^{n} q_i \, \frac{(r - r_i)}{\llbracket r - r_i \rrbracket^3}$$

We first examine the contribution of each charge

$$\mathrm{E}_1 = k\,\frac{\mathrm{r}-(1,1,1)}{[\![\mathrm{r}-(1,1,1)]\!]^3},$$

$$\mathrm{E}_2 = k\,\frac{\mathrm{r}+(1,1,0)}{[\![\mathrm{r}+(1,1,0)]\!]^3},$$

$$\mathrm{E}_3 = k\,\frac{\mathrm{r}-(2,0,1)}{[\![\mathrm{r}-(2,0,1)]\!]^3},$$

Now we must combine them.

$$\mathrm{E} = k\sum_{i=1}^{n} q_i\,\frac{(\mathrm{r}-\mathrm{r}_i)}{[\![\mathrm{r}-\mathrm{r}_i]\!]^3} = k\,\frac{\mathrm{r}-(1,1,1)}{[\![\mathrm{r}-(1,1,1)]\!]^3} + k\,\frac{\mathrm{r}+(1,1,0)}{[\![\mathrm{r}+(1,1,0)]\!]^3} + k\,\frac{\mathrm{r}-(2,0,1)}{[\![\mathrm{r}-(2,0,1)]\!]^3}.$$

We can find the field at any point by specifying the position vector. For example, at the origin, (0, 0, 0), we have,

$$\mathrm{E} = k\,\frac{(0,0,0)-(1,1,1)}{[\![(0,0,0)-(1,1,1)]\!]^3} + k\,\frac{(0,0,0)+(1,1,0)}{[\![(0,0,0)+(1,1,0)]\!]^3} + k\,\frac{(0,0,0)-(2,0,1)}{[\![(0,0,0)-(2,0,1)]\!]^3},$$

$$= \;k\,\frac{-(1,1,1)}{\sqrt{(-1)^2+(-1)^2+(-1)^2}^{\,3}} +$$

$$k\,\frac{(1,1,0)}{\sqrt{(1)^2+(1)^2+(0)^2}^{\,3}} + k\,\frac{(2,0,1)}{\sqrt{(2)^2+(0)^2+(1)^2}^{\,3}},$$

$$= \;k\,\frac{-(1,1,1)}{\sqrt{3}^{\,3}} + k\,\frac{(1,1,0)}{\sqrt{2}^{\,3}} + k\,\frac{(2,0,1)}{\sqrt{5}^{\,3}},$$

$$= \;k\,\frac{-(1,1,1)}{3\sqrt{3}} + k\,\frac{(1,1,0)}{2\sqrt{2}} + k\,\frac{(2,0,1)}{5\sqrt{5}},$$

$$= \;k\,\frac{-(1,1,1)+\;(1,1,0)+(2,0,1)}{3\sqrt{3}\;2\sqrt{2}\;5\sqrt{5}},$$

$$= \;k\,\frac{(2,0,2)}{30\sqrt{30}},$$

$$= \left(\frac{k}{15\sqrt{30}}, 0, \frac{k}{15\sqrt{30}} \right).$$

Theories of matter

At a fundamental level, matter is never really a point-like particle. Think about it this way, what is the density for a point-like particle? The volume is 0, so the density must be infinite. This cannot be real. Ultimately, we must try to explain matter as something other than a point-like particle.

We all know that the matter we experience is made up of particle-like constituents. Ordinary matter is, in fact, made up of *atoms*. Sometimes these atoms combine to form *molecules* and sometimes they form into ordered shapes that are not strictly molecules called *lattices*. Sometimes these particles have excess charges and they are no longer called atoms, instead they are called *ions*. Atoms and ions are themselves made up of more fundamental particles (electrons, protons, neutrons, etc.), as are certain kinds of exotic matter. These topics are governed by the quantum mechanical theory of matter. Quantum theories are so bizarre that they require an extensive rewiring of our brains through the gradual application of successively weird ideas, it is not convenient to jump right into those ideas.

We will take the view, at least initially, that we may treat objects as collections, some number n, of particles. It is important to realize that these objects are not to be considered as open clouds of particles, instead they are continuous distributions of matter. Each particle will be given a designation, say, p_i, where i is the label of the particle. Here we assume that i will be a sequence from 1 to n. The distance between any two particles is a vector whose components are the respective distances in terms of the coordinate system under consideration. Thus the distance between particles 1 and 2, would be the symbol d_{12}.

Here are the simplest physical arguments of matter theory. We note that there is a new notation used, $\prod_{i=1}^{n} x_i = x_1 x_2 \ldots x_n$, this is the product of all x.

You can learn more about the details of this theory of matter in [6].

Argument	Name	Formula	Explanation
117	Total Mass	$M = \sum_{i=1}^{n} m_i$	This is just the sum of all masses in the system under study.
118	Reduced Mass	$\mu = \frac{\prod_{i=1}^{n} m_i}{M}$	This allows us to think of the mass of a system as if it were one body instead of n bodies.
119	Center of Mass	$\mathbf{R} = \frac{\sum_{i=1}^{n} m_i \, \mathrm{r}_i}{M}$	When we think of a system of n particles as a single body, the center of mass is the place in the system that can be considered as the location of the reduced mass. This is the position of that is our representation of the system of particles.

The first formulation of matter is to consider all objects as continuous (unbroken) collections of particles, as stated above. There are two special cases of this formulation. The first is where the distances between particles are considered constant, this is called *rigid body mechanics*. The second special case is where the distances between particles are allowed to change, this is called *continuum mechanics*. Continuum mechanics can be divided into the study of elastic solids (*elasticity*) and liquids and gases (*fluid dynamics*). The next formulation occurs when we consider the presence of heat in matter, this is *thermodynamics*. If we apply the notion that heat is a measure of the internal energy of the collection of particles within an object, this is called *kinetic theory*. If we drop the assumption of a continuous distribution and consider the object as an average of the particles within, this is called *statistical mechanics*. If we consider the atoms that comprise matter, this is *quantum mechanics*. Beyond this we have molecular physics and atomic physics, the way that atoms, ions, molecules, and lattices form the matter we experience is the subject of *condensed matter physics*. When we consider the structure of the atom as a nucleus of dense matter surrounded by electrons, the study of that dense nucleus is called *nuclear physics*. If we consider electrons, protons, neutrons, and other bizarre particles, then we enter into *elementary particle physics*. Current ideas indicate that elementary particles might be vibrating strips of energy called *strings*, thus we have *string theory*. Even more bizarre notions indicate that everything might be made up of bits of information stuck to the surface of tiny volumes, this is called the *holographic principle*. The study of the physical properties of information, begun by the engineer Claude Shannon, is called *information theory*. Attempting to apply information theory to quantum systems leads us to *quantum information theory* and *quantum computing*. As we can see, the study of matter takes us from the world of every day experience down to the smallest imaginable scales.

This leads us to ask the question, "How do fields interact with matter?" At its simplest level, and that can be pretty complicated, we have the interaction of light with matter, this is *optics*.

Optics can be seen as a specialization of the interaction of electromagnetic radiation with matter. When we consider continuous distributions of matter, this is *continuum electrodynamics*. One very special interplay between continuous distributions of ionized matter and electromagnetic fields is *plasma physics*. When we consider quantum mechanical descriptions of matter and its interaction with fields, we have *quantum field theory*. A special area of interest is the theory of light interacting with matter at the quantum level, this is *quantum optics*. The most successful theory of the interactions of fields with matter, from the point of view of a complete theory, is the *general theory of relativity*; describing gravity as the curvature of space and time caused by the presence of continuous distributions of matter and energy, and how the matter and energy move or flow within that curvature. At the present time, though it is the subject of intense research, there is no quantum theory of gravity.

Applied physical theories

The use of physics to describe the properties and phenomena of astronomical bodies is called *astrophysics*. The study of stars is then *stellar astrophysics*, the matter between stars is *interstellar astrophysics*, planetary systems is *planetary astrophysics*, the study of galaxies is *galactic astrophysics*, the matter between galaxies is *intergalactic astrophysics*. The application of mechanical theories is called *celestial mechanics*. The application of field theories of gravity is called *relativistic astrophysics*, and the application of electromagnetic theory is called *radiative astrophysics*. The application of elementary particle physics to astronomical situations is called *high energy astrophysics*. The study of the origins, present and future states, and the properties of the universe as a whole is called *cosmology*.

The use of physics to study planetary atmospheres is, reasonably enough, called *atmospheric physics*. This is divided into the study of atmospheric motions called *atmospheric dynamics*, heat in the atmosphere called *atmospheric thermodynamics*, electromagnetic fields in the atmosphere called *atmospheric electrodynamics*, and the effects of electromagnetic radiation in the atmosphere called *atmospheric radiation*. Most of these use the principles of fluid mechanics as a basis, since the atmosphere behaves like a fluid.

The application of physics to the study of living systems is called *biophysics*. Within this branch of physics we have the motions of biological systems, this is called *biomechanics*. The study of electromagnetic fields in biological systems is called *bioelectromagnetics*. The study of thermal properties of biological systems, particularly molecular systems, is called *bioenergetics*. The study of the properties of biomolecules is, reasonably enough, called *biomolecular physics*.

Chemistry has been heavily influenced by physics. Depending on the exact ratio of chemistry to physics you will find yourself studying *physical chemistry* or *chemical physics*. These subjects are further divided by the application of thermodynamics to chemistry, called *thermochemistry*, the application of quantum mechanics to chemistry, called *quantum chemistry*, the application of electrodynamics to chemistry, called *electrochemistry*, and the application of dynamics to chemistry, called *chemical dynamics*. The application of physics to the study of materials in general is called *materials science*.

Modern technology is, for the most part, based on the principles of electric circuits and electronic devices. The principles of electrodynamics directly apply to electric and magnetic circuits in what is collectively called *circuit theory*. The application of quantum mechanics and condensed matter physics has brought forth the subject of *electronics*. The instrumentation of electronics has been applied to studying electromagnetic waves through the study of *signals analysis*. The application of mechanics has developed *systems theory*.

The application of mechanics to practical matters of engineering is called, reasonably enough, *engineering mechanics*. The use of mechanics, fluid mechanics, and thermodynamics to the design of machinery is called *mechanical engineering*. The application of nuclear physics to modern technology, including reactors and particle accelerators, is called *nuclear engineering*.

The application of physics to geology is called *geophysics*. The study of earthquake and other waves in the Earth is called *seismology*. The study of the shape of the Earth is called *geodesy*. The study of the electromagnetic fields of the Earth is called *geoelectrics* and *geomagnetics*. The application of physics to the study of groundwater systems is called *physical hydrology*. The application of physics to the study of oceans is called *physical oceanography*.

Things to do for Day Five

Write down five functions of time. Assume these functions are the position function, determine the velocity and acceleration. Assume the same functions are acceleration functions, then determine the velocity and position.

Write down five functions of time in a Cartesian coordinate system. Assume these functions are the position vectors, determine the velocity and acceleration vectors. Assume the same functions are acceleration vectors, then determine the velocity and position vectors. Take the partial time derivative of each vector.

Write down five functions of x, y, and z, treat these as scalars. Determine the gradient of each.

Write down five vector functions of x, y, and z. Take the inner product of each possible pair. Determine the divergence of each of the five vectors. Determine the norm of each vector. Take the vector product of each possible pair. Determine the curl of each vector.

Conclusions

In this writing I have presented the three basic theories of physics; the particle theory, the field theory, and the theory of matter. The particle theory starts us thinking about the fundamental quantities of physics. Field theory extends these concepts to entire regions under study. Matter theory can take either a particle or field approach.

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