# Electrostatics

I. Charge and Force
- Coulomb's Law
- conservation of charge
- quantization of charge

**II. Electric Fields**
- field strength
- motion of charged particles
- field lines
- distributions of charge

| | The student will be able to: | HW: |
|---|---|---|
| 1 | Relate electrical phenomena to the motion and position of the fundamental charge found on electrons and protons and explain process of charging in terms of conduction or induction and relate to properties of conductors and insulators. | 1 – 6 ✓ |
| 2 | State and apply Coulomb's Law to solve problems relating force and separation of discrete charges and recognize the Coulomb as the SI unit of charge and *e* as the elementary quantum of charge. | 7 – 15 ✓ |
| 3 | Define and apply the concept of electric field in terms of force acting on a charge within the field and solve related problems | 16 – 19 |
| 4 | Solve problems involving the motion of a charged particle in a uniform electric field. | 20 – 24 |
| 5 | Determine the electric field produced by a discrete charge or a set of such charges and solve related problems. | 25 – 29 |
| 6 | State and apply the rules for sketching electric fields. | 30 |
| 7 | Determine the electric field produced by a continuous charge distribution and solve related problems. | 31 – 42 |

# Electric Fields

a ~~figment~~ reality of our imagination…

A **field** is a region where a particular force has influence. There are many types of fields in physics: gravitational fields, magnetic fields, electric fields, etc.

**Field strength** is defined as the amount of force per unit of affected property.

A field is visualized as a series of vectors or lines. The direction of the force that results from the field determines the direction of the field.

# Electric Field

An electric field is defined as the amount of electrostatic force per charge:

$$\vec{E} = \lim_{q_t \to 0}\left(\frac{\vec{F}}{q_t}\right)$$

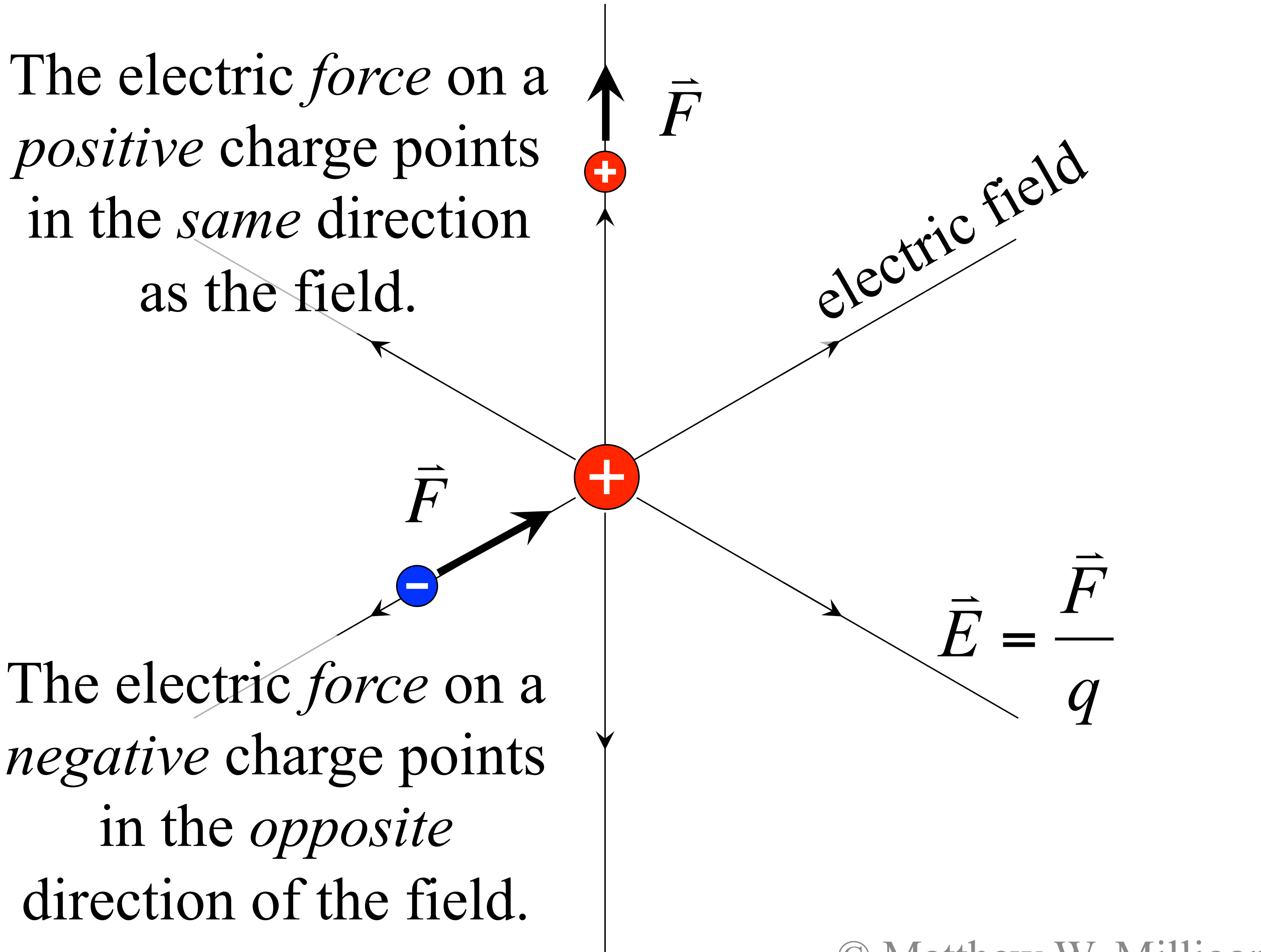
where: $E$ = electric field
$F$ = force on "test charge"
$q_t$ = test charge in field

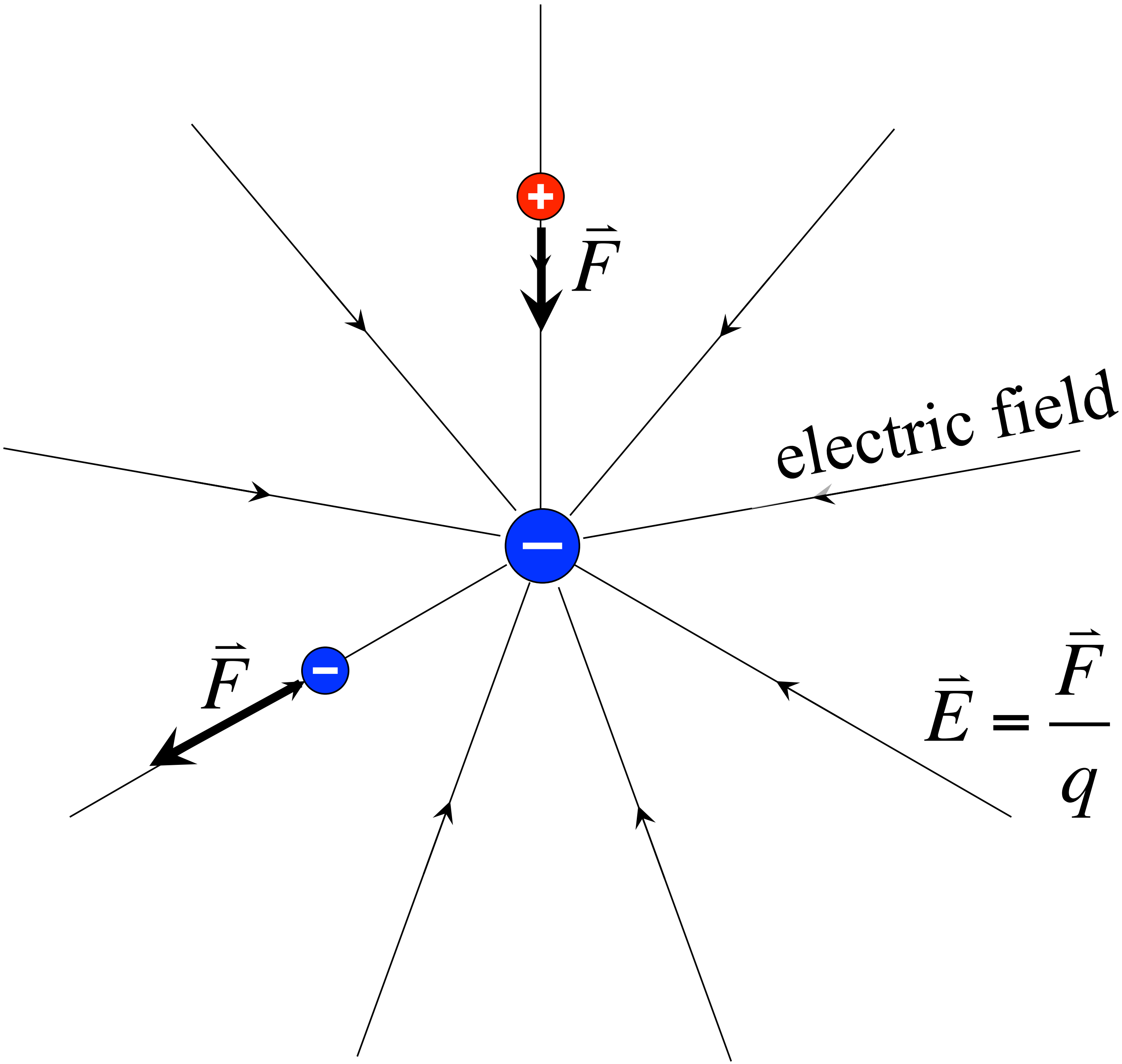
# Electric Field

The force on a charge, *q*, within a known electric field, ***E***, is given by:

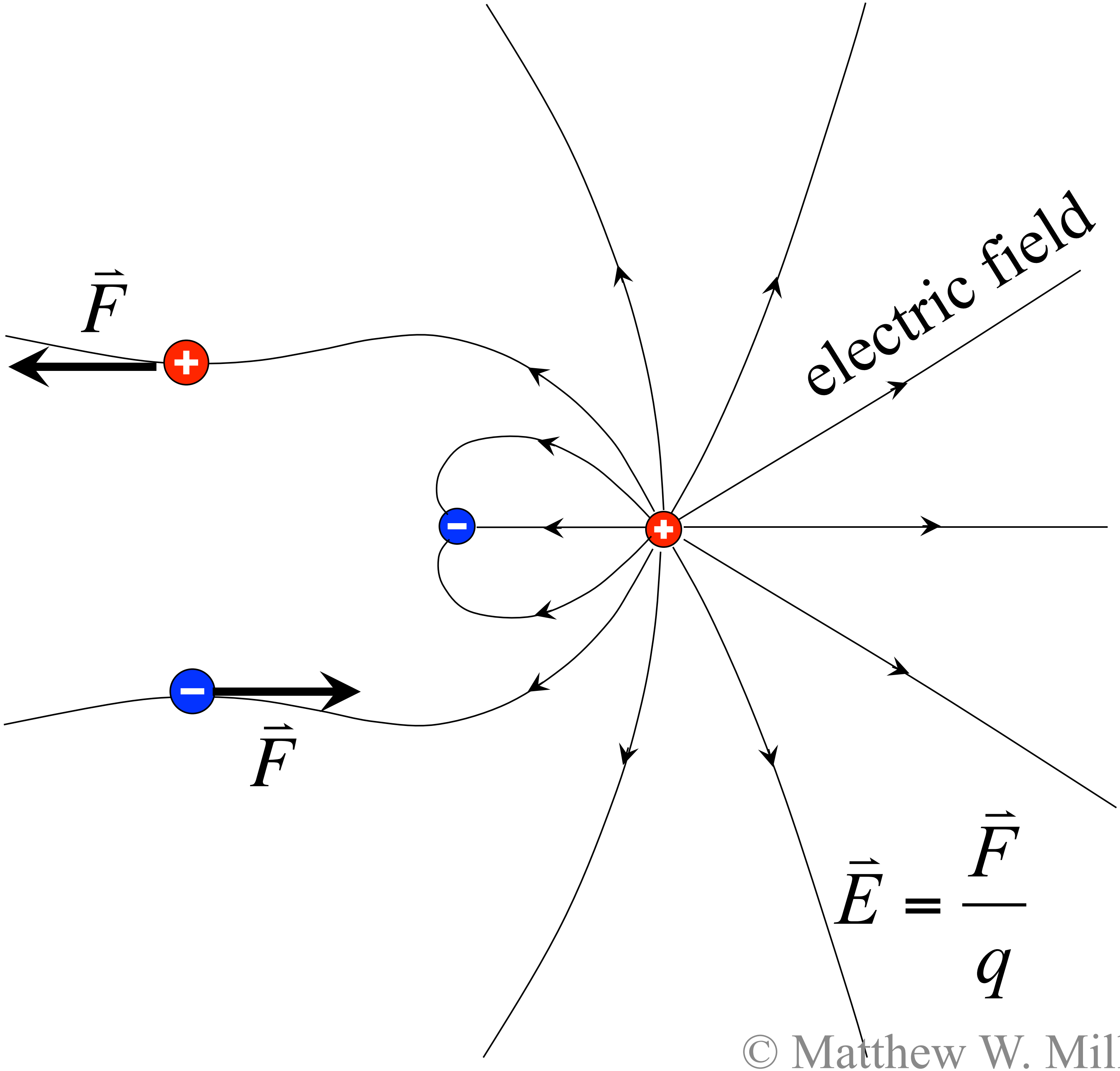
$$\vec{F} = q\vec{E}$$

(assuming that *q* does not have an effect on ***E***)

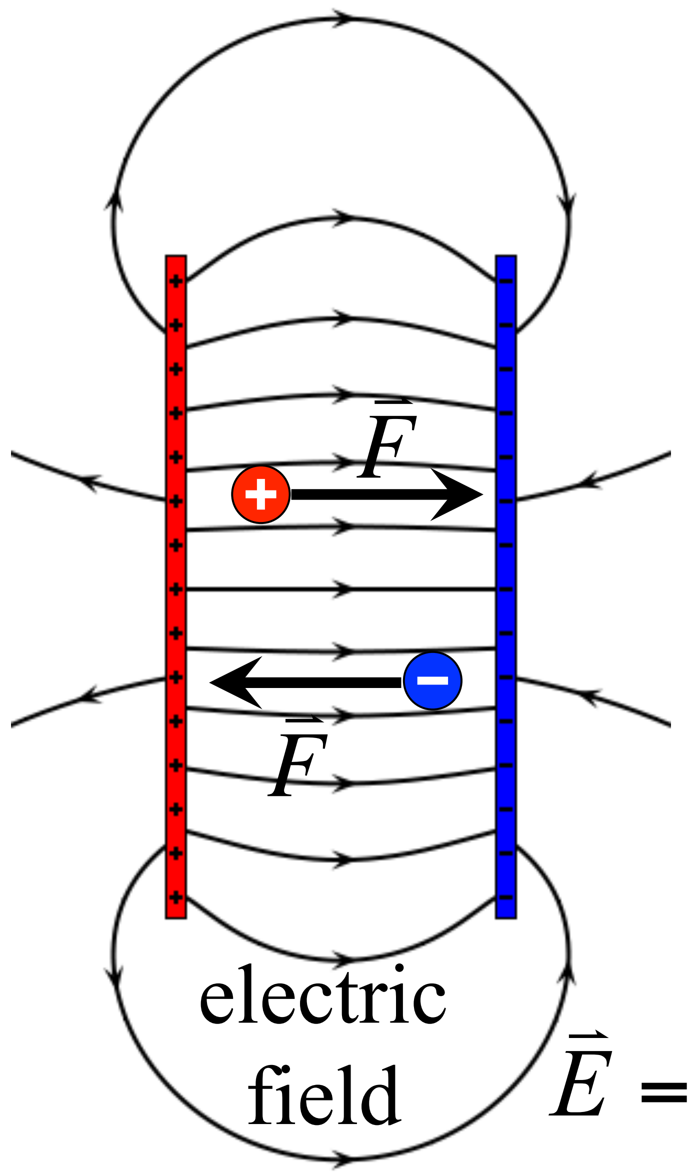

The electric *force* on a *positive* charge points in the *same* direction as the field.
$\vec{F}$
electric field
$\vec{F}$
$\vec{E} = \frac{\vec{F}}{q}$
The electric *force* on a *negative* charge points in the *opposite* direction of the field.
© Matthew W. Milligan



$\vec{F}$
electric field
$\vec{F}$
$\vec{E} = \frac{\vec{F}}{q}$


$\vec{F}$
electric field
$\vec{F}$
$\vec{E} = \frac{\vec{F}}{q}$

# Electric Field – Parallel Plates




$$\vec{E} = \frac{\vec{F}}{q}$$

Credit: Geek3, Wikipedia

| | The student will be able to: | HW: |
|---|---|---|
| 1 | Relate electrical phenomena to the motion and position of the fundamental charge found on electrons and protons and explain process of charging in terms of conduction or induction and relate to properties of conductors and insulators. | 1 – 6 ✓ |
| 2 | State and apply Coulomb's Law to solve problems relating force and separation of discrete charges and recognize the Coulomb as the SI unit of charge and *e* as the elementary quantum of charge. | 7 – 15 ✓ |
| 3 | Define and apply the concept of electric field in terms of force acting on a charge within the field and solve related problems | 16 – 19 ✓ |
| 4 | Solve problems involving the motion of a charged particle in a uniform electric field. | 20 – 24 ✓ |
| 5 | Determine the electric field produced by a discrete charge or a set of such charges and solve related problems. | 25 – 29 |
| 6 | State and apply the rules for sketching electric fields. | 30 |
| 7 | Determine the electric field produced by a continuous charge distribution and solve related problems. | 31 – 42 |

# Sources of Electric Fields

- Any charged object “creates” a surrounding electric field.
- Said charge could be referred to as the “source” of the field.
- It is often required to determine the electric field as a function of the source charge(s).

# Electric Field

The electric field produced by point charge:

$$\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r}$$

where: $E$ = electric field
$r$ = position relative to $q$
$q$ = point charge (or spherically symmetric charge distribution)

# Electric Field

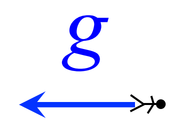

$$E = k\frac{Q}{r^2}$$

where: $Q$ = charge of the field's *source* (spherically symmetric charge)

$r$ = distance between centers

$k$ = Coulomb's Law constant

# Gravitational Field



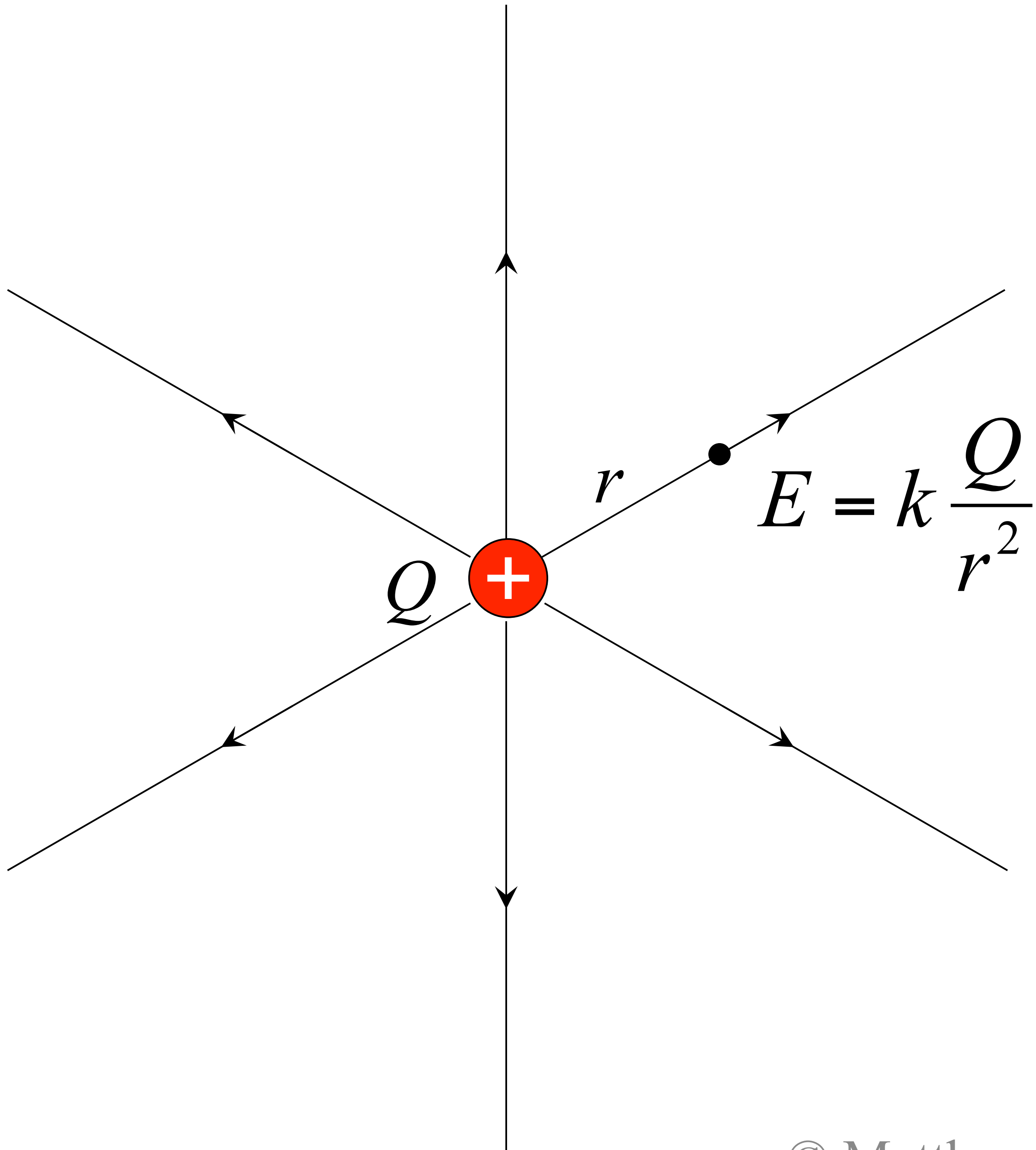

$$g = G\frac{M}{r^2}$$

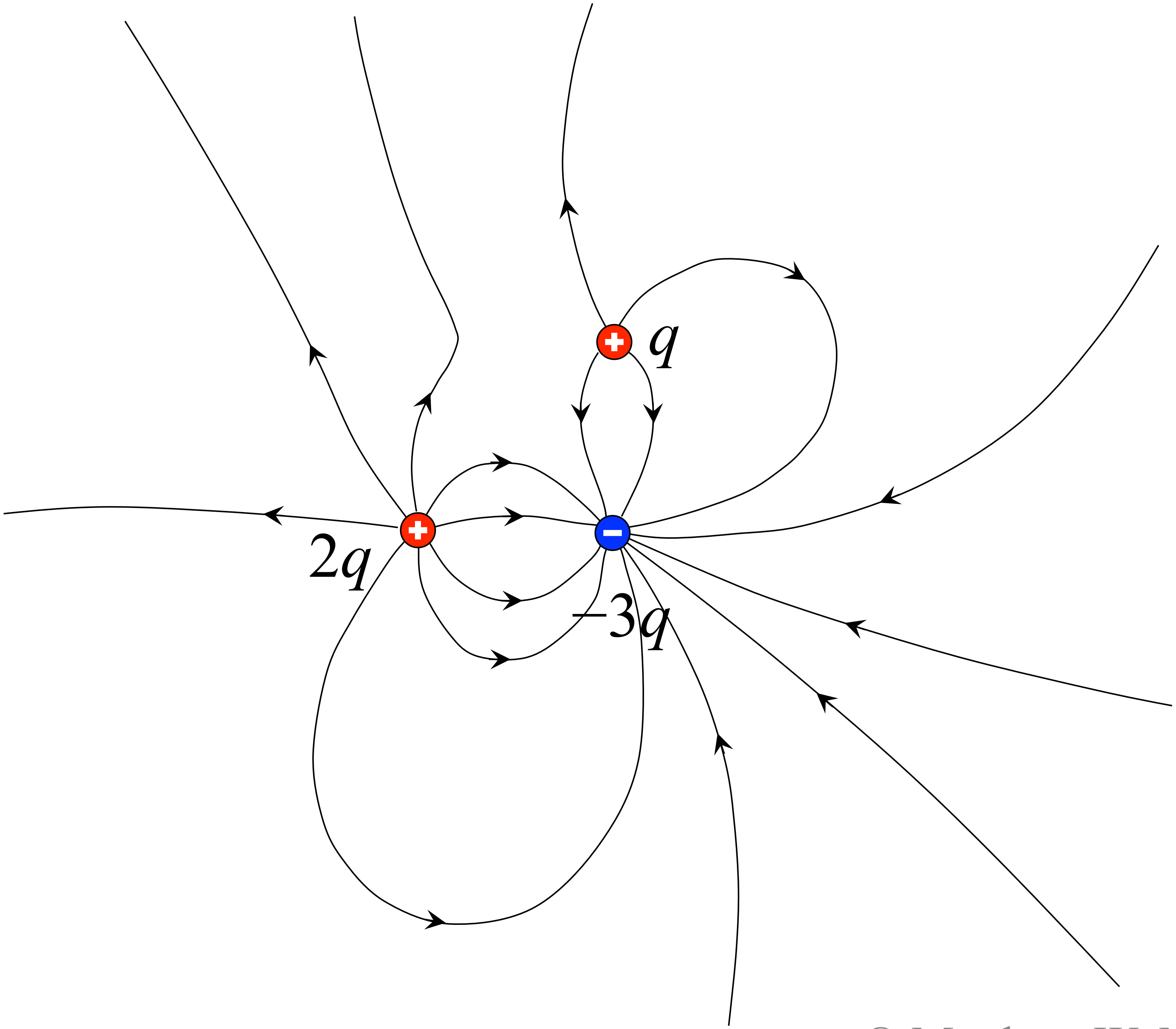
where: $M$ = mass of the field's *source*
$r$ = distance between centers
$G$ = universal gravitational constant:
$6.674 \times 10^{-11}$ m$^3$/kg s$^2$

| Gravitational Force: | Electrostatic Force: |
| --- | --- |
| $$F_G = G\frac{m_1 m_2}{r^2}$$ | $$F_E = k\frac{q_1 q_2}{r^2}$$ |
| $$F_G = mg$$ | $$F_E = qE$$ |
| $$g = G\frac{M}{r^2}$$ | $$E = k\frac{Q}{r^2}$$ |

Note the many similarities between gravitational force and field and electrical force and field.


E = ?


r
Q
$E = k\frac{Q}{r^2}$


q
2q
−3q

# Superposition Principle

- An electric field produced by multiple charges can have complex properties.
- This net electric field can be thought of as a superposition of individual fields.
- The net electric field is the vector sum of the individual fields produced by each charge.

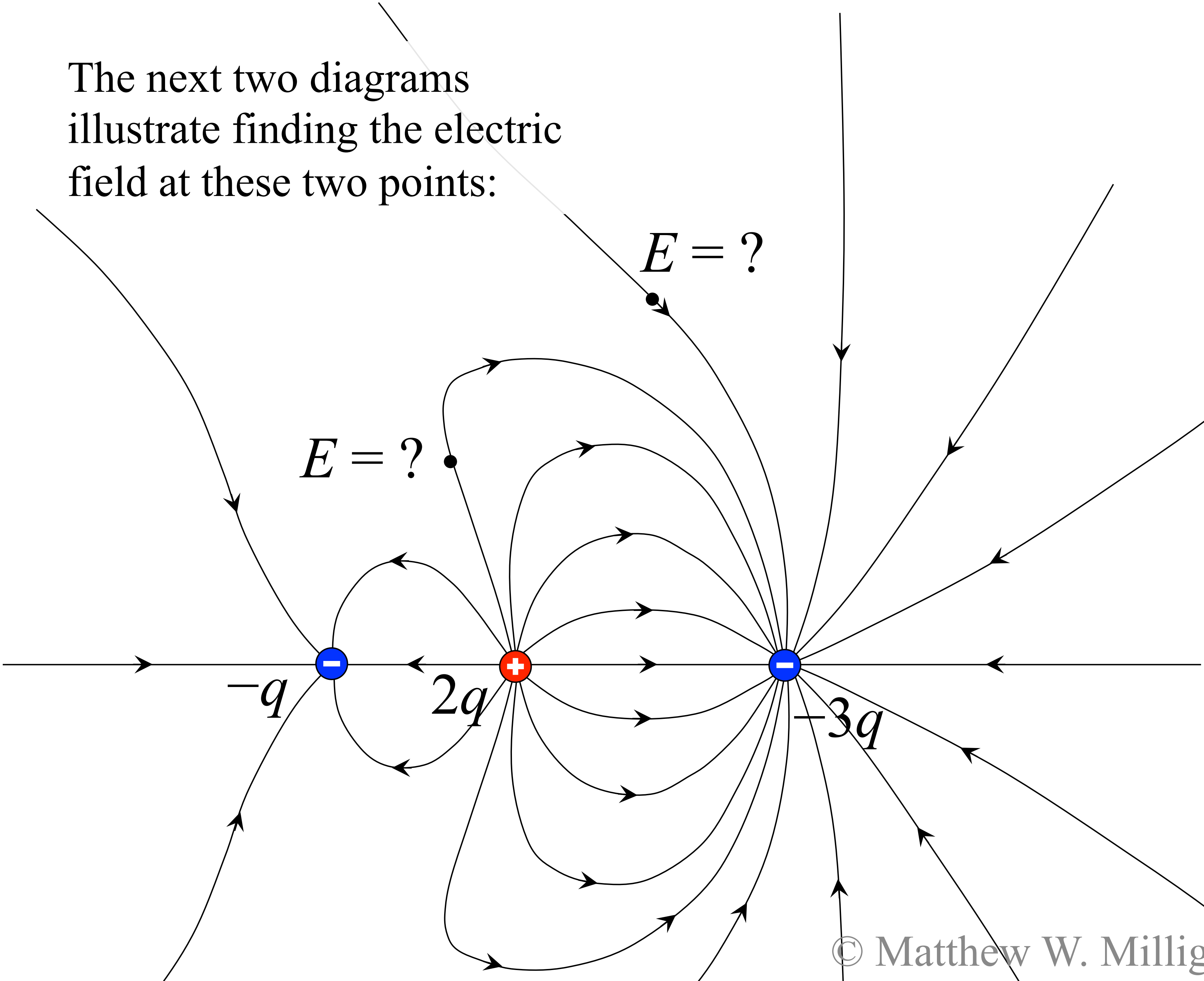
# Electric Fields of Charge Distributions

Electric field of a distribution of point charges:

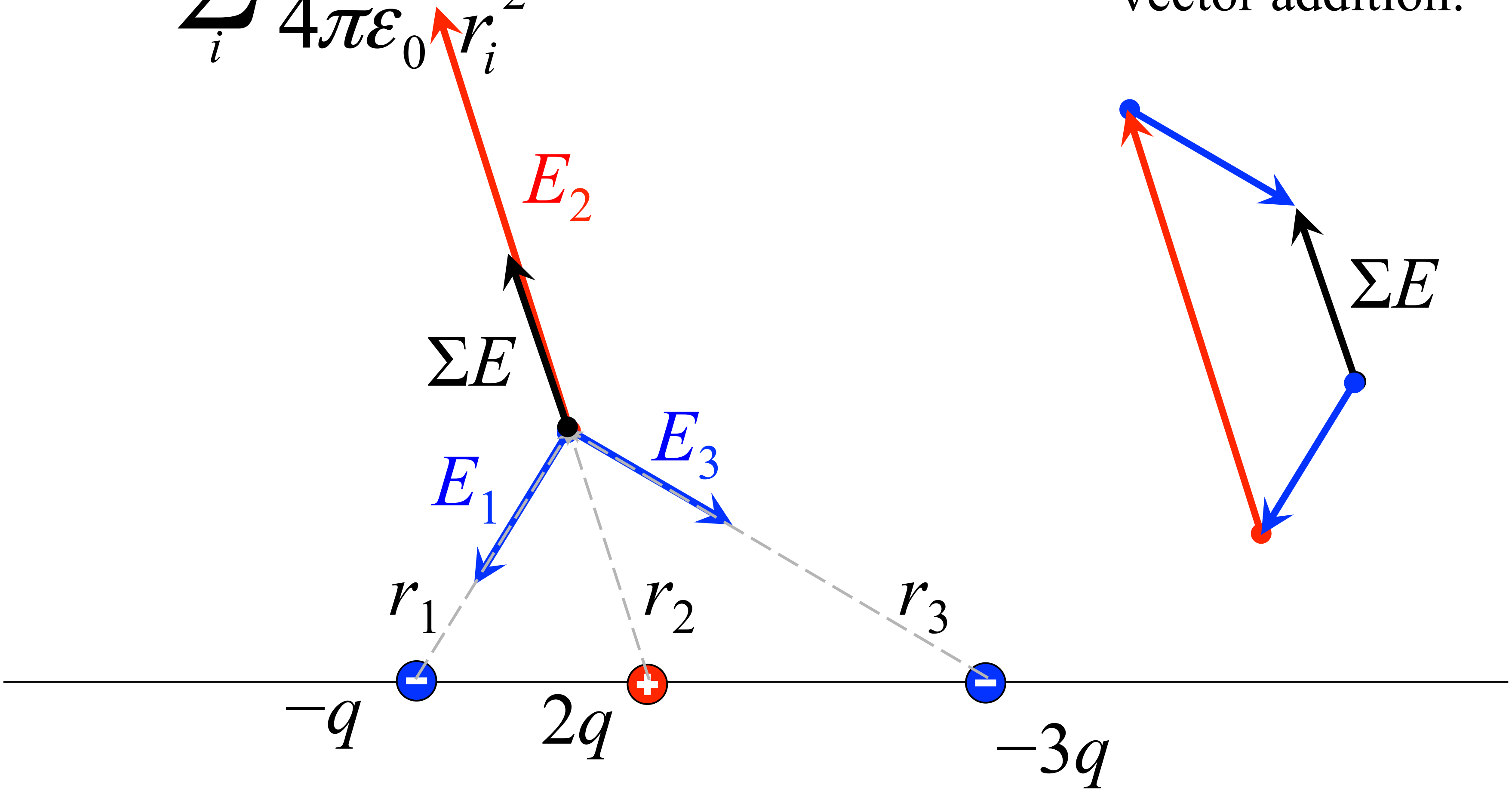
$$\vec{E} = \sum_i \frac{1}{4\pi\varepsilon_0} \frac{q_i}{r_i^2} \hat{r}$$

The vector sum of the individual fields contributed by each charge is the net electric field – this is called the **superposition principle**. There is a "superposition" of all the fields generated by the individual charges.

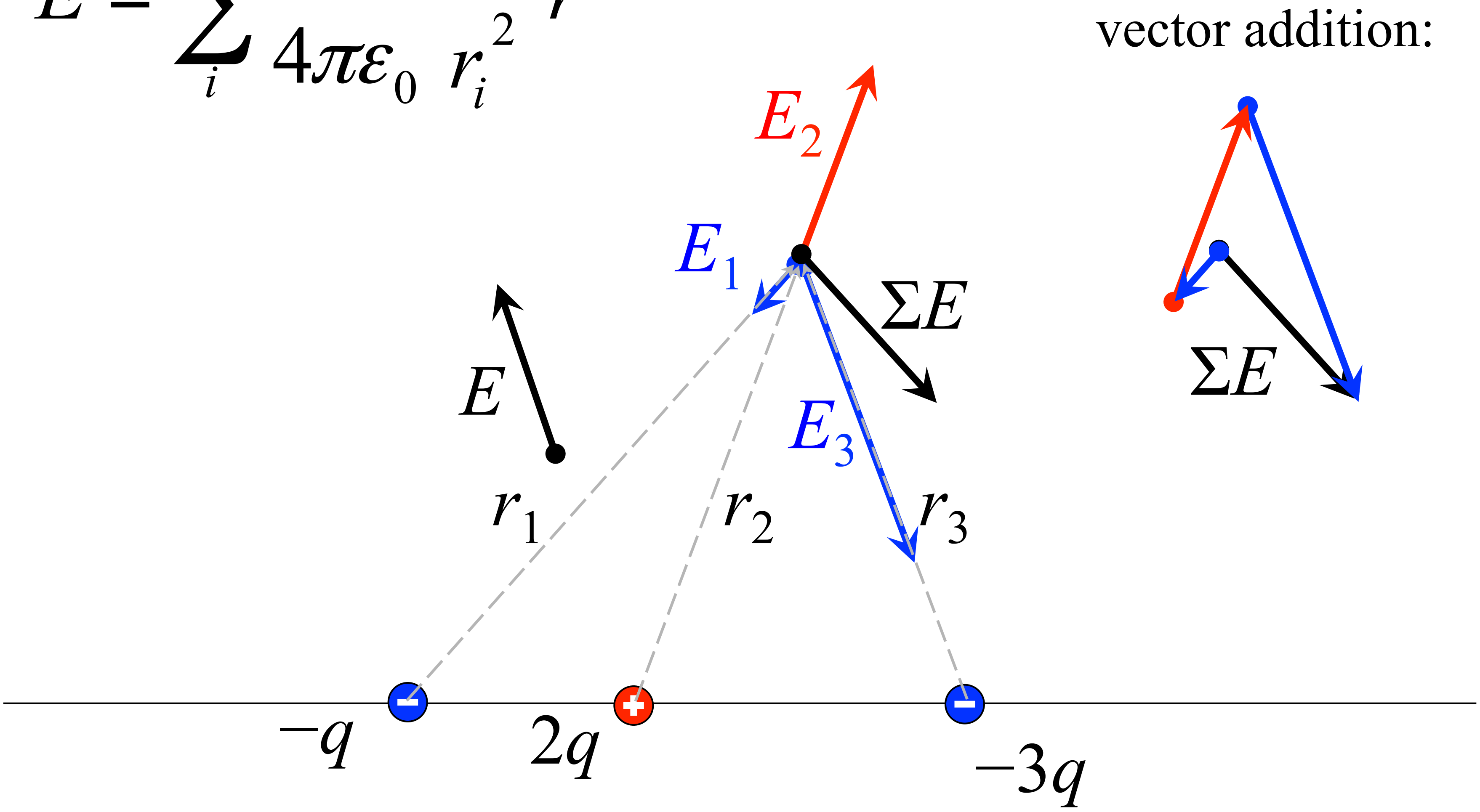
The next two diagrams illustrate finding the electric field at these two points:



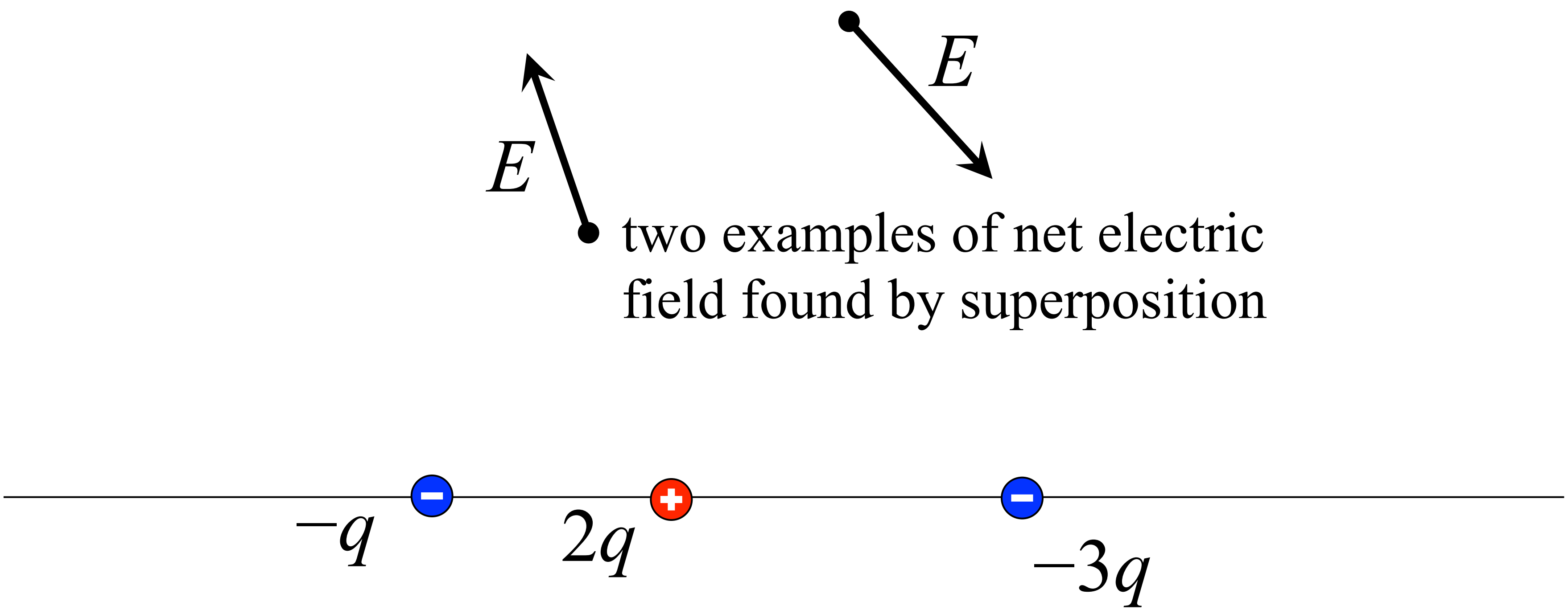
$$\vec{E} = \sum_i \frac{1}{4\pi\varepsilon_0} \frac{q_i}{r_i^{\,2}} \hat{r}$$



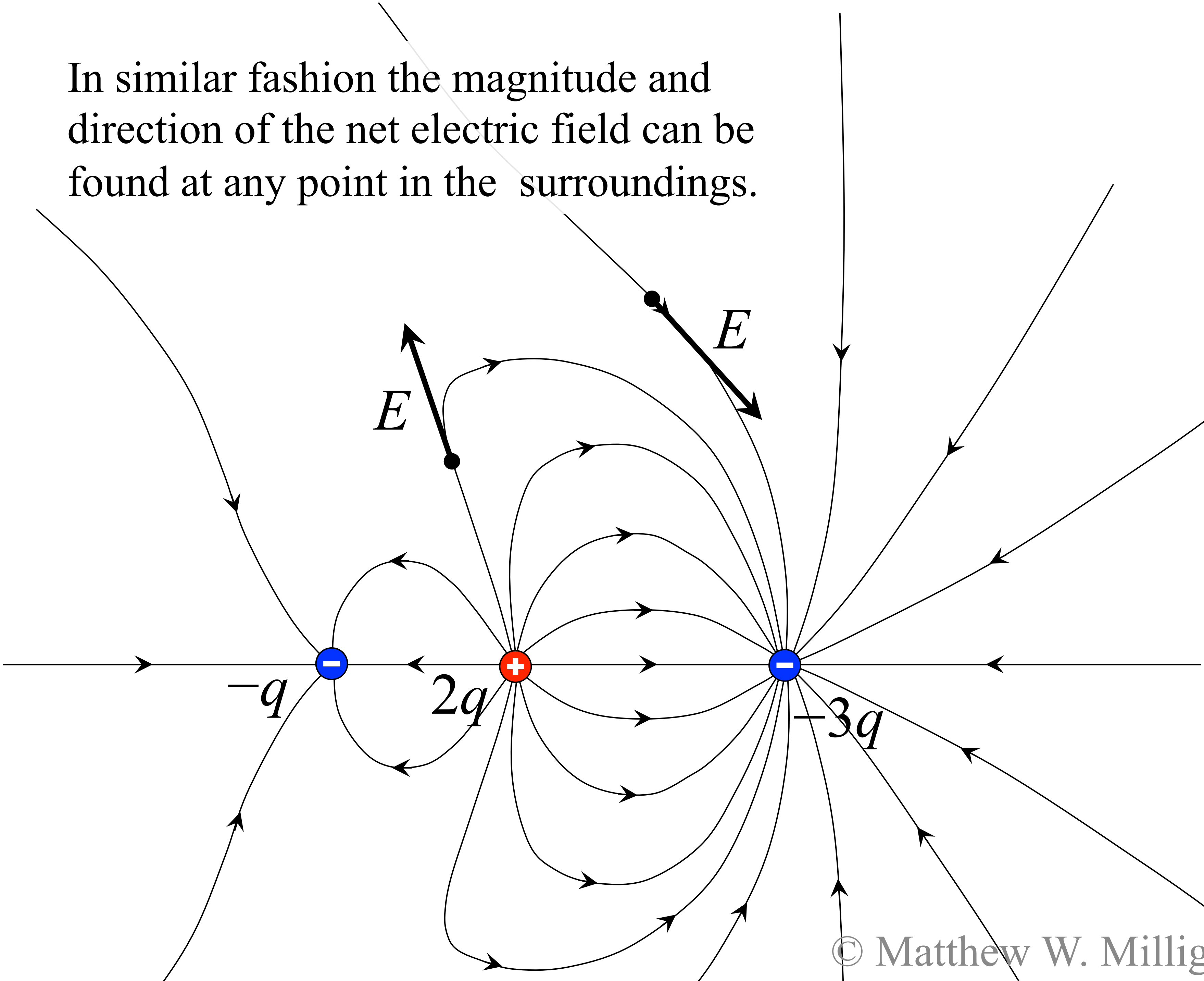
$$\vec{E} = \sum_i \frac{1}{4\pi\varepsilon_0} \frac{q_i}{r_i^2} \hat{r}$$



$$\vec{E} = \sum_i \frac{1}{4\pi\varepsilon_0} \frac{q_i}{r_i^{\,2}} \hat{r}$$

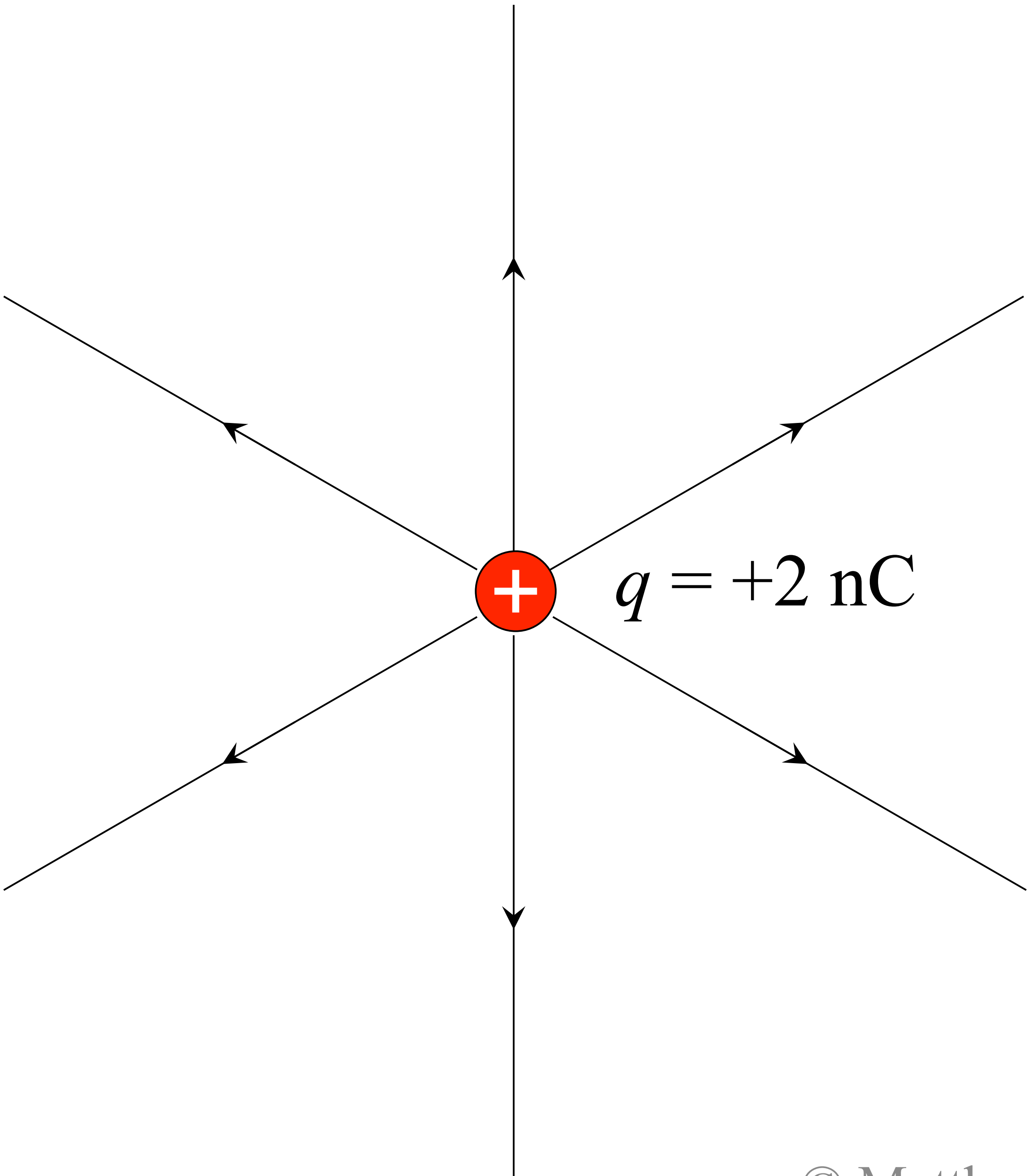


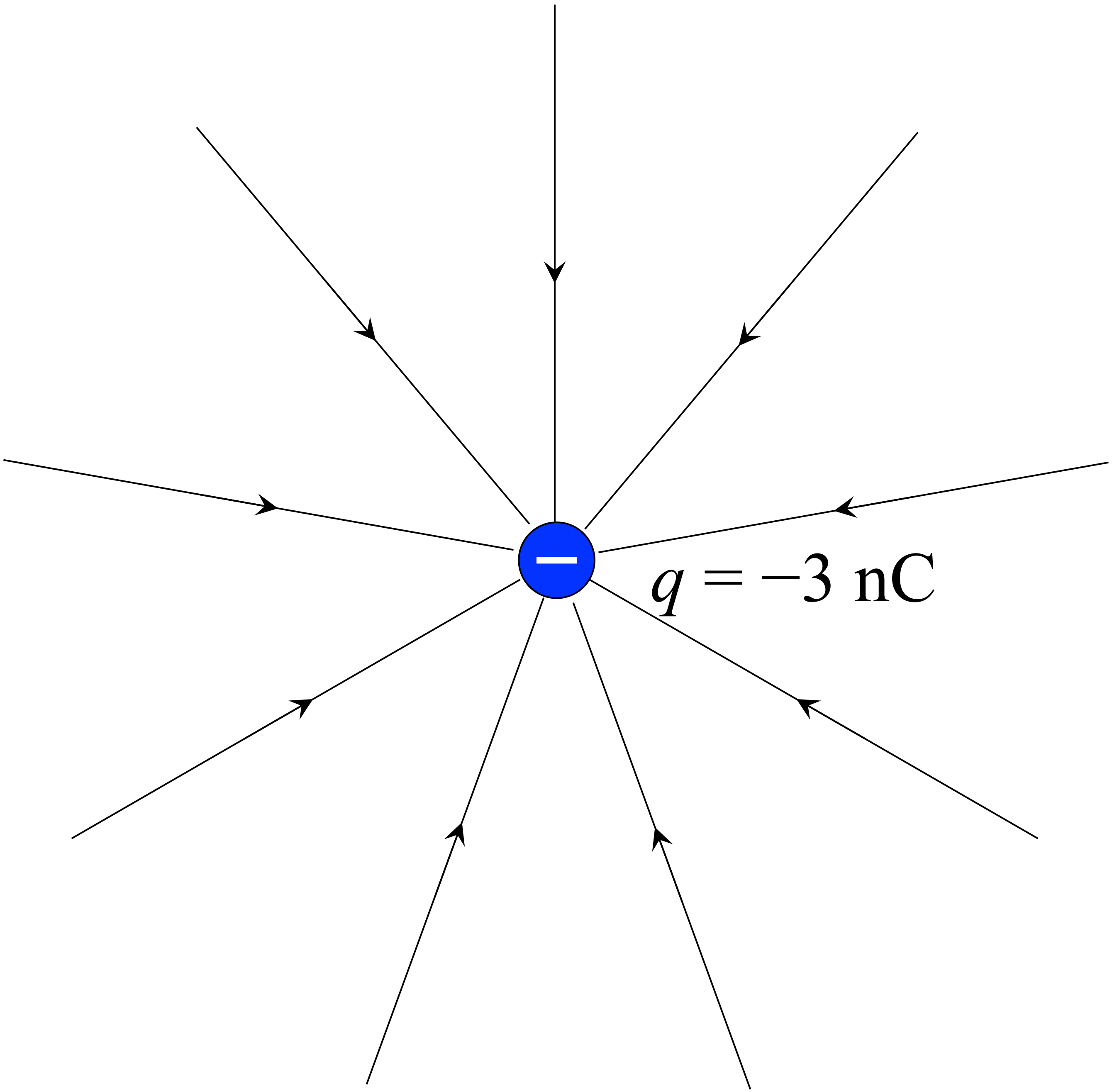
In similar fashion the magnitude and direction of the net electric field can be found at any point in the surroundings.



# Electric Field Lines

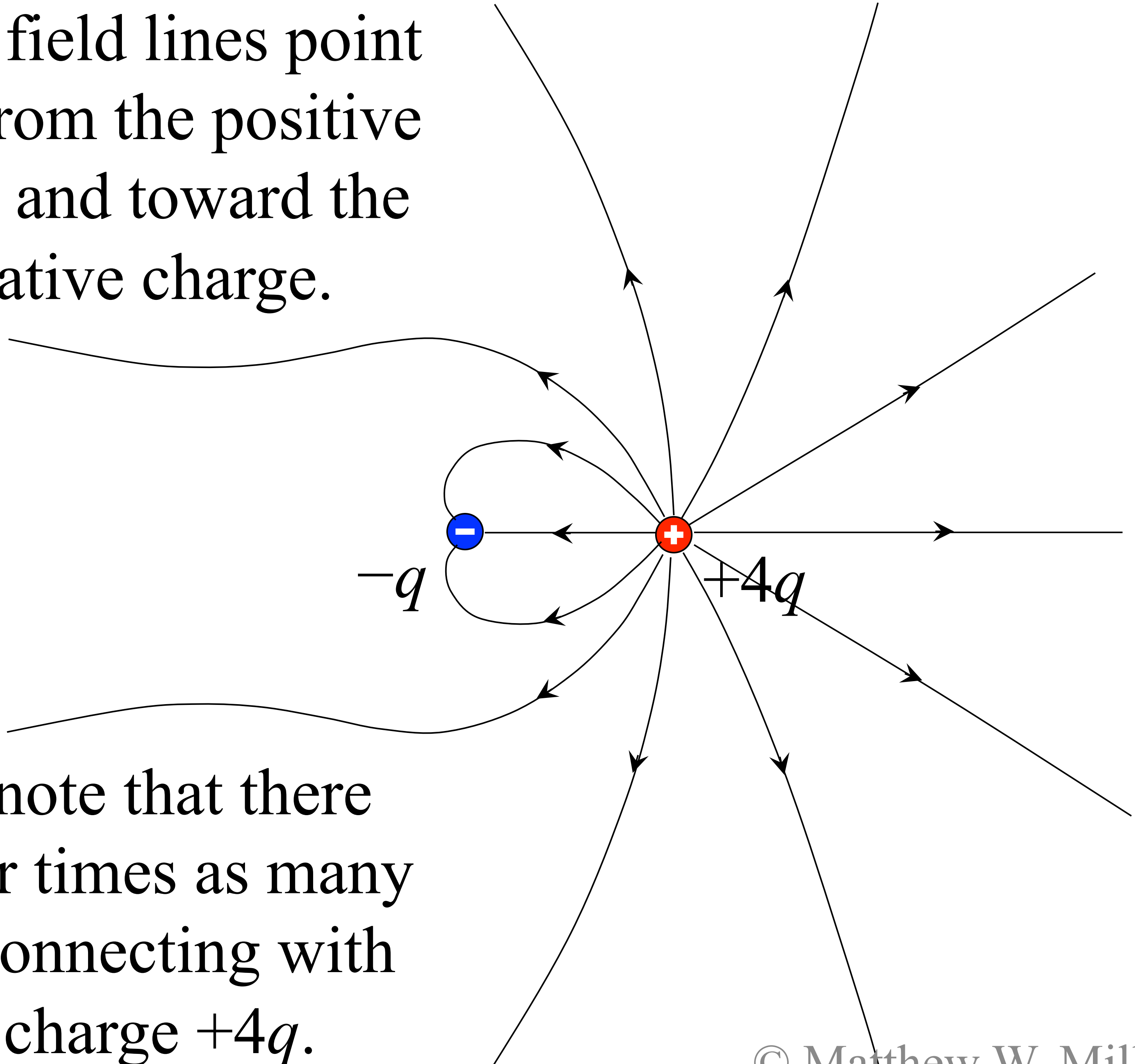
- The net electric force is tangent or collinear with a field line at any point.
- Lines point away from positive charges and toward negative charges.
- The number of lines originating or terminating on a charge is proportional to the amount of charge.
- Lines cannot cross or meet at any point!


q = +2 nC



−
q = −3 nC

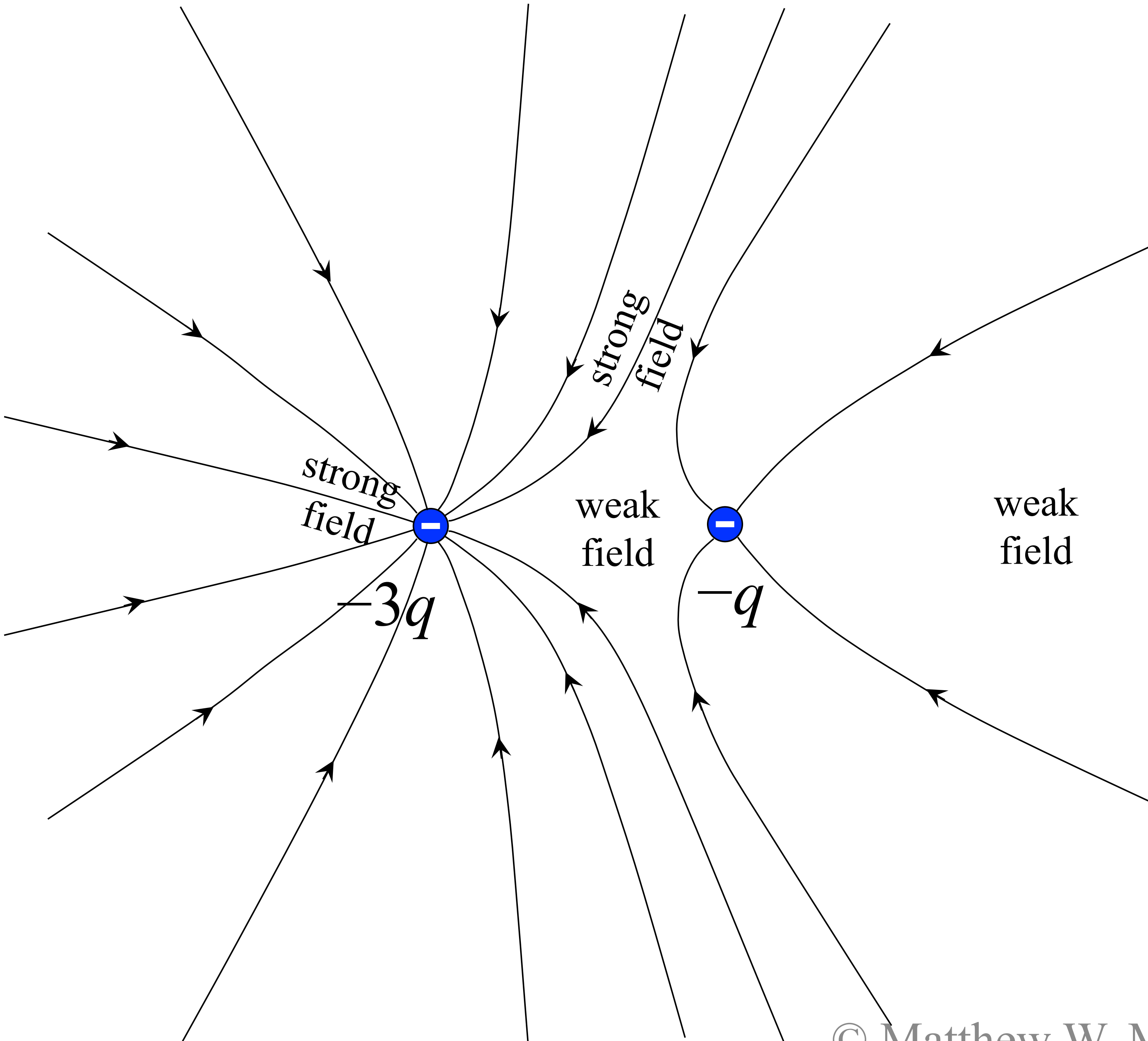
Notice field lines point away from the positive charge and toward the negative charge.




Also note that there are four times as many lines connecting with the charge +4*q*.

# Interpreting Field Diagrams

- Lines show direction a positive charge would *tend* to "flow" if immersed in the field. (A negative charge would behave oppositely.)
- More technically, the field at any point shows the direction of electric force and resulting acceleration. (A charged object does not necessarily "follow" any field line depending on other forces, initial velocity, etc.)
- Field strength is proportional to the number of lines per cross-sectional area. Where lines are closer together the field strength is greater.


strong
field
strong
field
weak
field
weak
field
−3q
−q

A positively charged particle released from rest *initially* would *follow* the field lines, but its inertia and velocity would result in the path shown as it continues to move as in the example shown here. At *any* location along the path the force and acceleration would always point in the direction of the electric field, assuming no other forces act.