# Equations to Remember

In physics we do not like to put much emphasis on rote memorization. However, I've found that too many students interpret this attitude as meaning that nothing needs to be remembered. We cannot discuss concepts and relationships if you do not have the basic laws and definitions firmly etched in your mind. That *should* follow naturally from studying and doing the homework, but to make sure, I have resorted to requiring memorization of a minimal set of equations and definitions. I do not care too much whether you remember where to put factors of 2 or $\pi$, or other constants. On the other hand, I *do* care very much, for example, that you know that the electric field from a point charge is proportional to the charge and falls off with distance as $1/r^2$. Note that this requirement can actually be helpful to you on the exams, as it allows me to assign some credit for an incorrect solution to a problem if, at least, you can write down the relevant equations correctly.

The shaded equations below are those that I require you to memorize. They correspond to the most basic physical laws (such as Coulomb's law), to basic definitions (such as Ohm's "law," which essentially corresponds to a definition of conductance), or to the simplest and most common configurations (such as the electric field at the surface of a conductor). Other equations, if needed, will be provided on the exams. Physical constants will also be provided, so their numerical values do not need to be memorized. You do need to know the names of the various SI units that we have been using, and you also need to know how to apply the equations to situations with multiple charges or current-carrying wires (e.g. use the principle of superposition to add fields and potentials).

- Coulomb's Law: $F = K \cdot \frac{|q_1 q_2|}{r^2}$ where $r$ is the distance between the point charges $q_1$ and $q_2$. You do *not* need to remember the value of $K$. Note that I have written here only the equation for the magnitude of the force, rather than the vector equation. That is because I recommend that you get the direction from drawing a picture and using simple rules, such as like charges repel, unlike charges attract (which you also must remember).

- Force on a point charge $q$ in an electric field: $\vec{F} = q\vec{E}$. From this and Coulomb's law it follows immediately that the magnitude of the electric field from a point charge $q$ is given by $E = K \cdot \frac{|q|}{r^2}$. You should also remember that the same equation applies to the field outside a spherically symmetric charge distribution.

- Potential energy of a charge $q$ at a point with electric potential $V$: $U = qV$.

- Relationship between electric potential and electric field: $\Delta V = V_{\vec{b}} - V_{\vec{a}} = -\int_{\vec{a}}^{\vec{b}} \vec{E} \cdot d\vec{\ell}$. However, for purposes of exam preparation, it is enough to understand the case of a uniform electric field pointing parallel to the displacement $\Delta s = b - a$: $\Delta V = -E\Delta s$ or $V_b - V_a = -E \cdot (b - a)$ (i.e. see equation 29.29, where they hide the minus sign by defining their coordinate $s$ to be in the direction opposite the field).

- The inverse of the previous equation: $E_x = -\frac{\partial V}{\partial x}$, $E_y = -\frac{\partial V}{\partial y}$, $E_z = -\frac{\partial V}{\partial z}$. Again, for exams it is enough to remember the 1-dimensional case: $E = -\frac{dV}{dx}$. In the case of a uniform electric field this would be $E = -\frac{V_b - V_a}{b - a}$, which is exactly the same relation as in the previous point.

- Potential due to a point charge: $V = K \cdot \frac{q}{r}$ where $r$ is the distance from the charge $q$ to the point where the potential is being evaluated. Combining this with the previous equation, you also have immediately the potential energy of a system of two point charges: $U = K \cdot \frac{q_1 q_2}{r}$, where $r$ is the distance between the charges.
- Potential in a uniform electric field: e.g. $V = Ex$ for the case where the electric field is pointing in the $-\hat{x}$ direction.
- Current in a metal wire: $I = -enAv_d$, where $n$ is the number of conduction electrons per unit volume, $-e$ is the electron charge, $A$ is the cross sectional area of the wire, and $v_d$ is the electron drift velocity. Here the minus sign just indicates that the conventional current is in the opposite direction from the electron flow. Also, you must know the definition of current density in the form $J = I/A$. Note that equations like this will most likely come up on exams in conceptual questions, rather than in plug-in-the-number problems. That is, what you need to understand is that current is proportional to the drift velocity, to the density of charge carriers, and to the cross sectional area, all of which should be highly intuitive and easy to remember.
- Ohm's law in the form $\vec{J} = \sigma\vec{E}$, which you can also think of as the definition of the conductivity $\sigma$. Also, the definition of resistivity $\rho = 1/\sigma$.
- The electric field of an infinite, uniform insulating plane of charge, $E = \frac{\eta}{2\varepsilon_0}$, and the electric field perpendicular to a conducting surface, $E = \frac{\eta}{\varepsilon_0}$, where in both cases $\eta$ is the surface charge density. You should also know that in both cases the field is perpendicular to the surface (on both sides in the case of an insulating plane). That is always true in electrostatics for a conducting surface. *For the insulating plane it is only true if the sheet of charge is uniform and infinite in extent.* You should also know that inside the conductor the electrostatic field is zero.
- Definition of the electric dipole moment, $p = qs$, with the direction going from the negative charge toward the positive charge.
- Definition of the magnetic dipole moment: $\mu = IA$, where $A$ is the area of the flat current loop and $I$ is the current flowing around it. Also, know how to get the direction of $\vec{\mu}$ from the right hand rule.
- Torque on an electric dipole in an electric field, $\tau = pE\sin\theta$, and potential energy of a dipole in a uniform electric field, $U = -pE\cos\theta$.
- Torque on a magnetic dipole in a magnetic field, $\tau = \mu B\sin\theta$, and the potential energy of a magnetic dipole in a uniform magnetic field, $U = -\mu B\cos\theta$. Notice how similar these equations are to the corresponding electric-dipole equations.
- Definition of capacitance: $C = Q/\Delta V$, where $\Delta V$ is the potential difference across the capacitor, and $Q$ is the charge stored on the capacitor. For a capacitor with 2 plates, $Q$ is the charge on just one of the plates (don't count the charge twice).
- Capacitance of a parallel plate capacitor: $C = \varepsilon_0 \frac{A}{d}$. The main point here is to understand that the capacitance is proportional to the area of the plates and inversely proportional to their spacing.
- Potential energy stored in a capacitor: $U = \frac{1}{2}C(\Delta V)^2$

- Ohm's law: $I = \frac{1}{R} \cdot \Delta V$ and the resistance of a wire: $R = \rho \frac{L}{A}$
- Electrical power in general: $P = \Delta V \cdot I$. Note that simple application of Ohm's law to this expression yields the alternative expressions $P = I^2 R$ and $P = (\Delta V)^2 / R$ for power delivered to a resistor.
- Magnetic force on a moving charge: $\vec{F} = q\vec{v} \times \vec{B}$, or more simply, $F = |q| v_\perp B$ for the magnitude, where $v_\perp$ is the component of the velocity perpendicular to the magnetic field. (You need to know how to use the right-hand-rule for the direction of the force.)
- Magnetic force on a straight wire segment: $\vec{F} = I\,\vec{\ell} \times \vec{B}$, or more simply, the magnitude is given by $F = I\ell B_\perp$, where $B_\perp$ is the component of the field perpendicular to the wire.
- Magnetic field strength a distance $r$ from a long, straight wire carrying current $I$: $B = \frac{\mu_0}{2\pi} \cdot \frac{I}{r}$. You should be able to combine this equation with the equation in the previous point to get the force between two parallel wires: $F = \frac{\mu_0}{2\pi} \cdot \frac{I_1 I_2}{r} \ell$.
- Magnetic field of a solenoid: $B = \mu_0 n I$, where $n$ is the number of turns per unit length.
- Definition of magnetic flux: $\Phi_m = \int_{loop} \vec{B} \cdot d\vec{A}$. If the field is uniform and the loop lies in a plane, then this simplifies to $\Phi_m = BA\cos\theta$.
- Faraday's law of induction: $\mathcal{E} = -\frac{d\Phi_m}{dt}$. Note that rather than worrying about the minus sign, the direction of the EMF is best handled through use of Lenz's law.
- Definition of inductance: $\Phi_m = LI$, and equivalently, when combined with Faraday's law, $\mathcal{E} = -L\frac{dI}{dt}$.
- Energy stored in an inductor: $U = \frac{1}{2} L I^2$.
- Relation between peak and rms voltage (or current): $V_{\text{rms}} = \frac{V_{\text{peak}}}{\sqrt{2}}$.

In addition, you should know basic equations for kinematics that you've seen in our homework (motion under constant acceleration) and mechanics (definitions of work, kinetic energy, power, and momentum).