Power is vital to the operation of all the electronic parts on the robot, including the controller and the motors. With the structural subsystem as the robot’s skeleton, and the motion subsystem as the muscle, the power subsystem is the circulatory system—the heart and blood vessels that provide the rest of the robot with energy.
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squarebot parts & assembly

Vex robots use batteries as their source of energy. The power subsystem is comprised of batteries and the other components needed to support them.

Tips for battery use (see Battery Types and Battery Care in the Concepts to Understand section for details):
• Buy a Vex Power Pack or a good set of rechargeable AA batteries (more than one set if you want to be able to use the robot while the other set is charging)
• Buy a good battery charger
• Charge batteries fully before first use
• Dispose of batteries properly – not in the trash!

Collect and identify the parts from the list of materials below:

<table>
<thead>
<tr>
<th>materials</th>
<th>qty</th>
</tr>
</thead>
<tbody>
<tr>
<td>NiCd AA battery</td>
<td>14</td>
</tr>
<tr>
<td>battery holder with lid</td>
<td>1</td>
</tr>
<tr>
<td>transmitter battery box</td>
<td>1</td>
</tr>
<tr>
<td>keps nut</td>
<td>4</td>
</tr>
<tr>
<td>8-32 hex screw, 3/8”</td>
<td>4</td>
</tr>
</tbody>
</table>
squarebot parts & assembly, continued

- AA battery x 14
- Battery holder w/ lid x 1
- Transmitter battery box x 1
- 8-32 hex screw, 3/8" x 4
- Keps nut x 4

Inventor’s Guide
For Transmitter Assembly:
Open the battery lid.

Insert 8 AA batteries, paying close attention to the battery orientation indicated on the holder.

Close the lid.
3 For the Squarebot Battery Holder:
Remove the battery lid.

Insert batteries, paying close attention to the battery orientation indicated on the holder.
Positioning the Battery Holder on Squarebot:

Position the battery holder without the lid on top of the Squarebot.

Keep the lid off until the screws that secure the holder are in place.

Attach holder using four $\frac{3}{8}$" screws.

The final assembly should look like this:
Battery Power Indicators

Since there are two sets of batteries in the Vex system, there are two battery power indicators.

One is on the Transmitter, and displays the battery voltage remaining in the transmitter unit.

<table>
<thead>
<tr>
<th>Transmitter LED displayed voltage</th>
<th>Indicates...</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.4V</td>
<td>Transmitter batteries somewhat low. You will need to stop soon.</td>
</tr>
<tr>
<td>8.9V</td>
<td>Transmitter batteries very low (10 minutes or less remaining), stop unless absolutely necessary.</td>
</tr>
<tr>
<td>8.5V</td>
<td>Transmitter batteries depleted. Stop now.</td>
</tr>
</tbody>
</table>

The other indicator is the Batt. Power light on the front of the Micro Controller, which tells you when the batteries on board the robot need to be recharged.

<table>
<thead>
<tr>
<th>Battery Power Light Color</th>
<th>Indicates...</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>Onboard robot batteries are OK.</td>
</tr>
<tr>
<td>Red</td>
<td>Onboard batteries need to be recharged.</td>
</tr>
</tbody>
</table>
Due to the large amount of current that the robot will draw from the batteries, we recommend NiCd batteries for use with the Vex robot.

**VEX Power Pack**

The best way to provide for the energy needs of the Vex robot is with the Vex battery. The Vex Power Pack includes a 7.2V battery pack for the robot, a 9.6V battery pack for the radio transmitter unit, and a charger for both batteries.

The batteries are NiCd (Nickel-Cadmium chemical composition) rechargeables that provide significantly energy than comparable AA NiCd batteries.

The Vex Power Pack cells, will provide a constant reliable voltage until they are exhausted. Contrary to popular belief, NiCd batteries do not suffer from any sort of permanent “memory effect” (see Battery Care later in this chapter).

For installation instructions, consult the documentation included with the Vex Power Pack.
NiCd Rechargeable AA batteries

NiCd (Nickel-Cadmium chemical composition)

AA batteries are recommended for use in the Vex Robotics Design System. Modern NiCd batteries do not suffer from any sort of permanent memory effect.

You will need to purchase six AA batteries for the Micro Controller and eight AA batteries for the Transmitter (14 batteries total). You will also need to purchase an NiCd battery recharger (be sure to get one that specifically) charges NiCd batteries).

For battery installation instructions, see the beginning of this chapter.

Note: Disposing of NiCd rechargeable batteries in the trash is illegal in many countries and states.

Important: The EPA certified RBRC® Battery Recycling Seal on the nickel-cadmium (NiCd) battery indicates Innovation One voluntarily participates in an industry program to collect and recycle these batteries at the end of their useful life, when taken out of service in the United States or Canada. The RBRC program provides a convenient alternative to placing used NiCd batteries into the trash or the municipal waste stream, which may be illegal in your area. Please call 1-800-8-BATTERY for information on NiCd battery recycling and disposal bans/restrictions in your area. Innovation One’s involvement in this program is part of the company’s commitment to preserving our environment and conserving our natural resources.
Alkaline Rechargeable and Non-rechargeable AA batteries

Alkaline batteries are NOT RECOMMENDED for the Vex Robotics Design System, but can be used in the transmitter.

Alkaline technology was not designed to handle the high levels of current that a robot requires (i.e. they cannot provide power fast enough), so the robot may lose power and turn off at unpredictable times.

Alkaline batteries also provide a decreasing voltage as they are used up, so the level of power available to the robot falls as the batteries are drained.

NiCd batteries maintain their voltages reliably until they are almost completely empty.

Finally, alkaline batteries, even “rechargeable” ones, are not truly rechargeable (rechargeable alkalines lose power with every recharge, and need to be replaced frequently). This means that their replacement cost will become prohibitive over time.

This includes the newer alkaline batteries that claim to be “designed for use in high tech devices,” but still suffer from the same drawbacks which make all alkaline batteries impractical for robot use.
Battery Care

First Use
If you are using rechargeable batteries (and you should be!), remember to let them charge fully the first time before you use them because they are usually shipped uncharged. Be sure to let them reach full capacity in order to ensure a healthy battery charging cycle.

Memory Effect and Voltage Drop
A myth that often surfaces about rechargeable batteries is the “memory effect”. This refers to a mistaken belief that total battery capacity diminishes permanently by a failure to drain the battery to zero voltage and then recharge it to full. “Memory effect” does not exist in consumer devices, only in very specific laboratory conditions.

A real phenomenon called “voltage drop” does exist that can easily be mistaken for the fictitious “memory effect.” Voltage drop is a measurable phenomenon where a battery that is repeatedly “shallow discharged” (used only part way before recharging) will start delivering lower and lower voltages, and will run out sooner.

Discharge Cycles
The good news about voltage drop is that it is not permanent, and it is curable. If your batteries seem to be getting shorter life than usual, all you need to do is run them down until the Vex Robot Micro Controller automatically turns off, or the transmitter displays its low voltage warning (this will happen between 1 and 1.1V per cell—6.5V for the robot, 8.5V for the transmitter), then charge them back to full again. You may need to perform the drain/recharge process a few times, but your batteries should steadily improve in performance each time until they are back to full strength.

Never discharge a NiCd cell to less than .9-1.0V. By not discharging the batteries farther than this (known as “deep cycling”), you will avoid a condition that could potentially damage your batteries and/or charger.
Battery Care, continued

Overcharge/Trickle Charge
In addition to not excessively draining rechargeable batteries, you should also avoid overcharging them. Overcharging can cause permanent damage to the battery. It is important that you get a good NiCd charger that knows when to stop adding charge to the batteries. Once the battery has reached full charge, the charger should switch over into “trickle charge” mode, which is a low current mode that can be safely applied over a long period of time to maintain a full charge, or shut off the charger.

Temperature
Charging or draining batteries quickly will result in them heating up. Excessive heat can also cause permanent damage to the battery, and should be avoided. Also do not store batteries in high temperature conditions. If batteries are hot after charging or running, let them cool down before charging or running.

Age
Rechargeable NiCd batteries can be used over and over again for hundreds of battery cycles if properly maintained. However, all batteries will eventually wear out over time, and you should keep in mind that if you notice an old set of batteries is not performing as well as it used to, it may be time to get a fresh set.

Environmental Issues
The cadmium found in NiCd batteries is highly toxic, and should not be disposed of in the trash. It is illegal to do so in many countries and states. Check your local regulations for information on proper battery recycling procedures in your area.
Voltage and Energy

Any time something in the physical world has the potential to go from one location to another there is an opportunity for it to do some useful work along the way. When water runs over a cliff, it falls downward because gravity is pulling on it. A hydroelectric generator takes advantage of this by having the water turn a turbine along the way as it falls.

When the water was up on top of the cliff, it had a lot of "gravitational potential energy", energy that was stored in the water because it was high up even though gravity wanted to pull it downwards. After falling to the bottom of the cliff, it got rid of some of its gravitational potential energy. Normally, the energy that was given up by the water is wasted (it gets transformed into other forms of energy, like sound and heat as the water hits the bottom), but if the water runs through a hydroelectric generator, the generator instead takes the energy and transforms it into a form that is useful to us, as electrical energy.
Electrons have negative charges, and naturally move toward areas with positive charges because opposite charges attract. A battery is like the cliff. One end (the – side) holds electrons at an area where they have high potential energy, just like the top of the cliff. The other side (the + end) is like the bottom of the cliff, an area of low potential energy that the electrons would like to travel toward. “Voltage” is the term used to describe the difference in electrical potential energy between two regions, hence a 1.5V battery has 1.5 volts of difference between the region at the + end and the region at the – end.

Unlike the waterfall, however, the battery doesn’t just let the electrons travel freely from the high-energy end to the low-energy end. You need to provide a path for the electrons in order to let them get from one end to the other by connecting the battery to a circuit. The wire provides a path for electrons to get from the – side to the + side.

Warning: Never hook a wire directly from one end of a battery to the other as the battery will become extremely hot.
The last step in the process is to add the hydroelectric generator. Except instead of a generator, you will be harvesting the energy from the moving electrons, with motors that change the electrical energy into physical energy and computer chips that use the energy to power other circuits inside them.

This is, of course, a huge simplification of the way electricity really works in a circuit, but the ideas behind voltage should still be clear: that there are regions with different amounts of potential energy, that the battery is what maintains that difference, and that the rest of the electronic components in the robot are effectively drawing their power from the electrons that are trying to move from one region to the other.
Batteries in Series
Batteries can be stacked together in series to add their voltages together, like stacking cliffs to make a bigger cliff. This is how multiple AA batteries (which are 1.2-1.5V each) produce a single larger “battery pack” with a combined voltage of around 7.2V in the Vex system. The Transmitter does the same thing to achieve a voltage of 9.6V.

Battery Cells
Individual batteries (like a single AA) are often called “cells,” to distinguish them from the entire “battery” pack. Technically, a “battery” refers strictly to a collection of multiple cells, so what we have been referring to as a battery pack is a “battery”, and what we usually call a battery (like an AA battery) is technically not a battery, but a “cell”.

The word “cell” comes from the nature of the battery as a self-contained vessel for the chemical reaction necessary to produce a specific electrical voltage. The name comes from an early 1800’s battery design by Dr. William Cruickshank, in which a wooden box or trough was divided into “cells,” and each cell had a metal plate inserted into it to create the electrochemical reaction. A modern battery pack (multiple AAs in series, for instance), similarly, has multiple “cells” with separate chemical chambers, which work together to produce the overall “battery” voltage.
subsystem interactions

How does the Power Subsystem interact with...

...the Structure Subsystem?
- The structure subsystem generally provides a safe, protected place to secure the battery.
- On the Squarebot, the structure subsystem provides a mounting platform for the battery holder, on the underside of the chassis (see Power Subsystem building instructions).

...the Motion Subsystem?
- The Motion Subsystem’s motors and servomotors convert electrical energy into physical energy, and so they will of course need electrical energy to work with. This energy is ultimately supplied by the Power Subsystem’s batteries, but the motors do not plug into the batteries directly. Rather, the flow of power is directed by the Micro Controller, which decides how much power is allowed to flow from the Power Subsystem to the Motion components.

...the Sensor Subsystem?
- Sensors, like all electronic components, require power in order to function. Vex sensors draw power indirectly from the Power Subsystem through the Micro Controller (Logic Subsystem).

...the Control Subsystem?
- Broadcasting radio waves takes a significant amount of electrical power. The eight AA batteries (or 9.6V battery pack) installed in the Vex Transmitter provide the Transmitter with all the power it needs to operate its internal circuitry and send out radio waves carrying commands to the receiver.
- The RF Receiver module mounted onboard the robot, on the other hand, draws its power from the Power Subsystem indirectly, through the Micro Controller (which is part of the Logic Subsystem).

... the Logic Subsystem?
- Since the Micro Controller is a device that contains a large number of electronic components, including two computer microprocessors, it needs power, which it draws directly from its connection to the Power Subsystem.
- The other major function of the Micro Controller is to control the other subsystems on the robot. It does this by selectively routing power from the Power Subsystem batteries to the other subsystems’ components (like motors).
- The Power Subsystem battery holder (or battery pack) connects to the Micro Controller module using a two-pin connector inside a plastic housing, which is mechanically “keyed” to prevent it from being plugged in backward.
# power subsystem inventory

<table>
<thead>
<tr>
<th>component</th>
<th>qty</th>
</tr>
</thead>
<tbody>
<tr>
<td>battery holder with lid</td>
<td>1</td>
</tr>
</tbody>
</table>
The Vex Power Pack is designed to provide reliable high-performance power for the Vex Robotics Design System. The kit includes one 9.6V NiCd rechargeable battery pack for the RF Transmitter, one 7.2V NiCd rechargeable battery pack for the Micro Controller, and a charger that can charge either battery safely in 3 hours or less (6 hours for both batteries). See the Power Subsystem in the Inventor’s Guide for information on battery care.

In case you need even more power, you can purchase additional rechargeable batteries at your local electronics retailer.
1 Plug in the Battery Charger
NiCd cells, like the ones in the Vex Power Pack, will lose charge over time even when not used. Your batteries have spent time in shipping and on the store shelf, so you will need to charge them before first use, and whenever they get low.

Begin by plugging the AC/DC Adapter into a standard household wall socket (120V, 60Hz AC).

Plug the end of the adapter's cable into the back of the Battery Charger.

Note: The lights on the charger will not go on yet.

2 Plug the Battery Packs into the Charger
Plug the 7.2V Battery Pack into one of the two white ports on the front of the Battery Charger, and slide the pack so it rests securely in the battery slot.

Plug the 9.6V Battery Pack into the other port and let it rest in the corresponding slot.

The light on the front of the Charger indicates which battery is currently charging. The pack you plugged in first will charge first, and the other will automatically begin charging when the first one is done.

You can unplug the first battery anytime after it is charged without interfering with the charge of the second battery.

Unplug the charger from the wall when both batteries are done charging.

Safety First:
To understand how to reduce the risk of fire or electric shock, review the Vex Power Pack safety sheet located in Appendix C.
power pack

Vex power pack, continued

3 Remove the Battery Holder from the Transmitter

Once your batteries have finished charging, you can install them in place of the existing AA battery holders in the Transmitter and on the robot.

Slide the battery cover off the back of the Transmitter.

Lift the Transmitter Battery Holder out of the Transmitter housing. Be careful not to pull on the wire that attaches the Battery Holder to the Transmitter. Unplug the Battery Holder from the Transmitter Power Cable. Press down on the lever on the Transmitter Plug side to release the latch before separating the plugs.

4 Install the 9.6V Battery Pack inside the Transmitter

Plug the 9.6V Battery Pack into the transmitter's power socket where the Battery Holder was previously plugged in. Place the 9.6V Battery Pack inside the Transmitter. It will not take up the whole space; it rests in the larger side of the compartment.

Replace the Battery Cover on the Transmitter.
5 Mount the 7.2V Battery Pack on the Robot

Start by removing the AA Battery Holder.
Unplug the Battery Holder from the Micro Controller. Detach the Battery Holder by removing the cover and unscrewing the four screws that are holding it in place. Lift the Battery Holder up off the robot, and put it away somewhere safe.

Attach the Battery Strap. Use two 8-32 \( \frac{3}{8} '' \) screws and two keps nuts to secure the base of the strap.

Important: The EPA certified RBRC® Battery Recycling Seal on the nickel-cadmium (Ni-Cd) battery indicates Innovation One voluntarily participates in an industry program that collects and recycles NiCd batteries at the end of their useful life, when taken out of service in the United States or Canada. The RBRC program provides a convenient alternative to placing used Ni-Cd batteries into the trash or the municipal waste stream, which may be illegal in your area. Please call 1-800-battery for information on Ni-Cd battery recycling and disposal bans/restrictions in your area. Innovation One's involvement in this program is part of the company's commitment to preserving our environment and conserving our natural resources.

Note: Remove batteries if you will not be using the battery pack for more than a week as batteries can leak chemicals that can damage electronic parts.

Parts needed in this step:
- x1

Exploded View

Parts needed in this step:
- 8-32 \( \frac{3}{8} '' \) x2
- x2
5 Mount the 7.2V Battery Pack, continued

Attach the rechargeable battery pack to the desired location on the robot. The strap will go over the top, around, and under the battery and through the locking mechanism (as shown). Be sure the battery’s cord will be able to reach the power port on the Robot Controller.

Plug the 7.2V Battery Pack into the power (+ - ) port into the Micro Controller. Secure rechargeable battery pack with battery strap, pull till the battery is firmly attached.

Note: A second mounting strap could be used to keep the battery from slipping while the robot is in use.

Straps are reusable, just press and hold the lever to unlock and then pull out the strap.
The Battery Charger includes the following features:

- **Automatic Charging Current Selection** — automatically detects the battery voltage and selects the appropriate charging current.
- **Reverse Polarity Protection** — protects the charger and batteries when incorrectly installed.
- **Short Circuit Protection** — protects the charger and batteries against shorted batteries.
- **Automatic Power-Off** — turns off the charger to prevent overcharging.
- **Overcurrent Protection** — controls the charging current.

**Warm Batteries** - It is normal for the batteries to become warm during charging.

**Status Lights** - The lights on the Battery Charger will flash if there is a problem during charging with either the battery or the charger. Try a different battery on the port with the flashing light to determine whether the battery or the charger is causing the error.

**Operating Conditions** - Charge batteries in an area between 60 and 85 °F. Batteries do not fully charge when they are cold. If the area is too warm, the batteries can permanently lose their ability to charge.

**Unplugging** - To prevent damage to your charger and risk of shock, always unplug the AC/DC Transformer from the AC outlet before you unplug it from the charger.

**Battery and Charging Info: 9.6V Transmitter Power Pack**

<table>
<thead>
<tr>
<th>Battery Type</th>
<th>Battery Capacity</th>
<th>Charging Current</th>
<th>Charging Rate</th>
<th>Charging Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>NiCd</td>
<td>1000mAh</td>
<td>700mA</td>
<td>1 - 0.7 C</td>
<td>1.4 - 2.0 hrs</td>
</tr>
</tbody>
</table>

**7.2V Robot Power Pack**

<table>
<thead>
<tr>
<th>Battery Type</th>
<th>Battery Capacity</th>
<th>Charging Current</th>
<th>Charging Rate</th>
<th>Charging Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>NiCd</td>
<td>2000mAh</td>
<td>1000mA</td>
<td>1 - 0.5 C</td>
<td>1.4 - 2.8 hrs</td>
</tr>
</tbody>
</table>

**Maintenance** - Keep the charger dry; if it gets wet, wipe it dry immediately. Use and store the charger only in normal temperature environments. Handle the charger carefully; do not drop it. Keep the charger away from dust and dirt, and wipe it with a damp cloth occasionally to keep it looking new.

**Limited 90-day Warranty**

This product is warranted by Innovation One against manufacturing defects in material and workmanship under normal use for ninety (90) days from the date of purchase from authorized Innovation One dealers. For complete warranty details and exclusions, check with your dealer.

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