The only legal source of electrical energy for the ROBOT/HOSTBOT during the competition is one MK ES17-12 12VDC non-spillable lead acid battery, OR one EnerSys NP 18-12 battery, as provided in the 2011 KOP.
Current
Voltage
Resistance

P = power
V^2
R
R \times I^2
V \times I
\frac{P}{I}
\frac{V}{I}
\sqrt{\frac{P}{R}}
\sqrt{P \times R}
I = current
V = voltage
R = resistance
VRLA Batteries

- Valve Regulated (sealed)
- Lead Acid
- Deep cycle motive battery
- 10 A typical discharge
electrolyte

\[ \text{H}_2\text{SO}_4 \rightleftharpoons 2\text{H}^+ + \text{SO}_4^{2-} \]

anode

\[ \text{Pb} + \text{HSO}_4^- \rightleftharpoons \text{PbSO}_4 + \text{H}^+ + 2\text{e}^- \]

cathode

\[ \text{PbO}_2 + \text{HSO}_4^- + 3\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{PbSO}_4 + 2\text{H}_2\text{O} \]

overall

\[ \text{Pb} + \text{PbO}_2 + 2\text{H}^+ + 2\text{HSO}_4^- \rightleftharpoons 2\text{PbSO}_4 + 2\text{H}_2\text{O} \]

2.1 Volts
Inside the Battery

Discharge in any position, charge UPRIGHT
PbO$_2$ Cathode, Pb Anode
Matted Glass Fiber Separators
Each Battery is Unique
Know your batteries!

<table>
<thead>
<tr>
<th>Date</th>
<th>Voltage</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>19 Oct 2010</td>
<td>12.07 V</td>
<td></td>
</tr>
<tr>
<td>26 Oct 2010</td>
<td>12.85 V</td>
<td>+0.81</td>
</tr>
<tr>
<td>28 Oct</td>
<td>12.81 V</td>
<td>-0.04</td>
</tr>
<tr>
<td>31 Oct</td>
<td>12.79 V</td>
<td></td>
</tr>
<tr>
<td>10 Jan 2011</td>
<td>12.64 V</td>
<td></td>
</tr>
<tr>
<td>22 Jan 2011</td>
<td>12.02 V</td>
<td></td>
</tr>
<tr>
<td>31 Jan 2011</td>
<td>5.31 V</td>
<td></td>
</tr>
<tr>
<td>01 Feb</td>
<td>13.09 V</td>
<td></td>
</tr>
<tr>
<td>09 Feb 2011</td>
<td>12.76 V</td>
<td></td>
</tr>
<tr>
<td>10 Feb 2011</td>
<td>12.18 V</td>
<td></td>
</tr>
<tr>
<td>12 Feb 2011</td>
<td>12.64 V</td>
<td></td>
</tr>
<tr>
<td>12 Feb 2011</td>
<td>12.65 V</td>
<td></td>
</tr>
<tr>
<td>12 Feb</td>
<td>11.00 V</td>
<td></td>
</tr>
<tr>
<td>12 Feb</td>
<td>11.98 V</td>
<td></td>
</tr>
<tr>
<td>13 Feb</td>
<td>12.22 V</td>
<td>15 hrs.</td>
</tr>
<tr>
<td>14 Feb 07:40</td>
<td>13.11 V</td>
<td></td>
</tr>
<tr>
<td>17 Feb</td>
<td>11.92 V</td>
<td></td>
</tr>
<tr>
<td>18 Feb 07:05</td>
<td>11.92 V</td>
<td></td>
</tr>
<tr>
<td>15 00</td>
<td>13.11 V</td>
<td></td>
</tr>
<tr>
<td>19 Feb 19:26</td>
<td>12.91 V</td>
<td></td>
</tr>
<tr>
<td>19 Feb 23:00</td>
<td>12.22 V</td>
<td></td>
</tr>
<tr>
<td>20 Feb 09:30</td>
<td>12.27 V</td>
<td></td>
</tr>
<tr>
<td>21 Feb 11:30</td>
<td>12.28 V</td>
<td></td>
</tr>
<tr>
<td>22 Feb 09:20</td>
<td>12.69 V</td>
<td></td>
</tr>
<tr>
<td>22 Feb 15:15</td>
<td>12.93 V</td>
<td></td>
</tr>
<tr>
<td>22 Feb</td>
<td>12.89 V</td>
<td></td>
</tr>
</tbody>
</table>
Specifications

ES17-12

Specifications:
- Nominal Voltage (V): 12V
- Nominal Capacity: 18Ah
- 20hr rate (0.05A to 10.50V): 18Ah
- 10hr rate (0.05A to 10.50V): 17.1Ah
- Hour rate (3.08A to 10.25V): 15.3Ah
- 1C (18A to 9.80V): 8.1Ah
- 3C (9.4A to 9.80V): 6.3Ah
- Weight: 13.82 Lbs (6.283 kg)
- Internal Resistance (at 1kHz): 10 mΩ
- Maximum Discharge Current for 30 minutes: 360A
- Maximum Discharge Current for 5 minutes: 720A
- Operating Temperature Range:
  - Charge: 0°C to 32°F to 40°C to 104°F
  - Discharge: -15°C (5°F) to 50°C (122°F)
  - Storage: -15°C (5°F) to 40°C (104°F)
- Charge Retention (shelf life) at 20°C (68°F):
  - 1 month: 92%
  - 3 month: 90%
  - 6 month: 80%
- Charging Methods at 20°C (68°F):
  - Cycle use: Charging Voltage 14.4 to 15.0V
  - Maximum Charging Current: 5.4A
- Standby use: Float Charging Voltage 13.50 to 13.80V
- Life expectancy:
  - Cycle Use: 100% depth of discharge 200 cycles
  - 80% depth of discharge 255 cycles
  - 50% depth of discharge 500 cycles
- Standby Use:
  - 3-5 years
  - ABS (Option: 94-VHB & 94-V fire retardant case)
- Terminal: F3

MK Battery
1631 South Sinclair Street • Anaheim, California 92805
Tel: 800-577-9253 • Fax: 714-837-0818 • E-Mail: sales@mkbattery.com

Genesis NP
NP18-12B
NP18-12BFR
Sealed Rechargeable Lead-Acid Battery
12V, 17.2Ah

Dimensions:
- Dimensions: Inches
  - 10.75 x 6.90 x 5.50
Nominal Capacity

Q = i (Amps) x Time (hours)

Genesis NP18-12B
- Q = 17.2 A-hr
- 20 hour rate
- i = 0.86 A to 10.5V

MK ES17-12
- Q = 18 A-hr
- 20 hour rate
- i = 0.9 A to 10.5V
Capacity is not linear
How many Amps does the robot use?
## Estimate current > Calculate time

<table>
<thead>
<tr>
<th>Load</th>
<th>Minimum (A)</th>
<th>Maximum (A)</th>
<th>Estimate (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 each CIM motors</td>
<td>2 x 2.7</td>
<td>2 x 40</td>
<td>2 x10 = 20</td>
</tr>
<tr>
<td>compressor</td>
<td>0</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>arm motor</td>
<td>0.82</td>
<td>108.7</td>
<td>20</td>
</tr>
<tr>
<td>signal light</td>
<td>1.1</td>
<td>2.2</td>
<td>2</td>
</tr>
<tr>
<td>radio</td>
<td>1.0</td>
<td>2.5A</td>
<td>2.5</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>8.2</strong></td>
<td><strong>203.9</strong></td>
<td><strong>46</strong></td>
</tr>
</tbody>
</table>

Nominal Capacity @ 46A ~ 6.3 Ahr (MK Battery)
Discharge Time VS. Discharge Current (20°C)
<table>
<thead>
<tr>
<th>Battery</th>
<th>Starting Voltage</th>
<th>Ending Voltage</th>
<th>On-load Voltage</th>
<th>Time (min)</th>
<th>comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brady</td>
<td>?</td>
<td>?</td>
<td>?</td>
<td>18</td>
<td>Time not accurate</td>
</tr>
<tr>
<td>Tron</td>
<td>12.96</td>
<td>11.78</td>
<td>11.45</td>
<td>36</td>
<td>Mostly standby</td>
</tr>
<tr>
<td>Gwen</td>
<td>13.25</td>
<td>12.98</td>
<td>12.65</td>
<td>27</td>
<td>Mostly standby</td>
</tr>
<tr>
<td>David</td>
<td>12.95</td>
<td>12.67</td>
<td>12.32</td>
<td>23</td>
<td>Half driving, half playing, swapped out early</td>
</tr>
<tr>
<td>Silly-D</td>
<td>12.92</td>
<td>11.90</td>
<td>11.54</td>
<td>31</td>
<td>Half driving, half playing</td>
</tr>
</tbody>
</table>

Average current must be less!

\[ i = \frac{Q}{t} = 8.1 \text{ Ahr} \times 60 \text{ min/hr} / 29 \text{ min} = 17 \text{ A} \]
## Time per match?

<table>
<thead>
<tr>
<th>Time</th>
<th>Match</th>
<th>Red 1</th>
<th>Red 2</th>
<th>Red 3</th>
<th>Blue 1</th>
<th>Blue 2</th>
<th>Blue 3</th>
<th>Red Score</th>
<th>Blue Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:28 AM</td>
<td>1</td>
<td>2361</td>
<td>610</td>
<td>1075</td>
<td>1219</td>
<td>1305</td>
<td>2056</td>
<td>2</td>
<td>11</td>
</tr>
<tr>
<td>9:37 AM</td>
<td>2</td>
<td>854</td>
<td>1503</td>
<td>1565</td>
<td>1246</td>
<td>2185</td>
<td>2609</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>9:48 AM</td>
<td>3</td>
<td>2386</td>
<td>1310</td>
<td>772</td>
<td>2525</td>
<td>296</td>
<td>1535</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>9:55 AM</td>
<td>4</td>
<td>843</td>
<td>3396</td>
<td>771</td>
<td>781</td>
<td>1000</td>
<td>2200</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>10:05 AM</td>
<td>5</td>
<td>1114</td>
<td>3190</td>
<td>2505</td>
<td>3161</td>
<td>2702</td>
<td>1334</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>10:11 AM</td>
<td>6</td>
<td>772</td>
<td>843</td>
<td>296</td>
<td>854</td>
<td>1075</td>
<td>1246</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>10:17 AM</td>
<td>7</td>
<td>2609</td>
<td>1535</td>
<td>3396</td>
<td>1000</td>
<td>610</td>
<td>1305</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>10:24 AM</td>
<td>8</td>
<td>771</td>
<td>2625</td>
<td>1503</td>
<td>2361</td>
<td>2386</td>
<td>2200</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>10:31 AM</td>
<td>9</td>
<td>1565</td>
<td>1334</td>
<td>2185</td>
<td>1114</td>
<td>781</td>
<td>2702</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>10:37 AM</td>
<td>10</td>
<td>3161</td>
<td>2056</td>
<td>3190</td>
<td>1219</td>
<td>2505</td>
<td>1310</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>10:43 AM</td>
<td>11</td>
<td>296</td>
<td>1503</td>
<td>1334</td>
<td>1000</td>
<td>1114</td>
<td>772</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>10:49 AM</td>
<td>12</td>
<td>2386</td>
<td>2702</td>
<td>1565</td>
<td>1075</td>
<td>1219</td>
<td>3396</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>10:56 AM</td>
<td>13</td>
<td>2200</td>
<td>2609</td>
<td>771</td>
<td>3161</td>
<td>781</td>
<td>1305</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>11:04 AM</td>
<td>14</td>
<td>2625</td>
<td>2185</td>
<td>854</td>
<td>2361</td>
<td>3190</td>
<td>1305</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>11:11 AM</td>
<td>15</td>
<td>1246</td>
<td>1535</td>
<td>1310</td>
<td>2505</td>
<td>2056</td>
<td>8</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>11:18 AM</td>
<td>16</td>
<td>1075</td>
<td>3161</td>
<td>772</td>
<td>781</td>
<td>2185</td>
<td>1503</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>11:25 AM</td>
<td>17</td>
<td>771</td>
<td>3190</td>
<td>1535</td>
<td>1114</td>
<td>781</td>
<td>1305</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>11:31 AM</td>
<td>18</td>
<td>1334</td>
<td>2386</td>
<td>1305</td>
<td>1310</td>
<td>2056</td>
<td>1565</td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td>1:05 PM</td>
<td>19</td>
<td>2702</td>
<td>1000</td>
<td>2505</td>
<td>3396</td>
<td>2625</td>
<td>2</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>1:13 PM</td>
<td>20</td>
<td>1219</td>
<td>2609</td>
<td>2361</td>
<td>843</td>
<td>2200</td>
<td>1246</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>1:19 PM</td>
<td>21</td>
<td>1000</td>
<td>1075</td>
<td>2056</td>
<td>772</td>
<td>2625</td>
<td>1565</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>1:25 PM</td>
<td>22</td>
<td>1305</td>
<td>1535</td>
<td>2200</td>
<td>2361</td>
<td>771</td>
<td>2702</td>
<td>8</td>
<td>1</td>
</tr>
</tbody>
</table>

**New match every 6.8 minutes**

18 matches 2.25 minutes playing

4.55 minutes waiting
How much Q is used in a match?

Battery capacity required for a match?

\[ Q_{\text{match}} = Q_{\text{playing}} + Q_{\text{waiting}} \]

\[ = (2.25 \text{ min} \times 17 \text{ A}) + (4.55 \times 8 \text{ A}) = 74.65 \text{ A-min} \]

How many matches is a battery good for?

matches = \( Q / Q_{\text{match}} \)

\[ = 8.1 \text{ Ahr} \times 60\text{min/hr} \times 486 \text{ A-min} / 74.65 \text{ A-min} \]

\[ = 6 \text{ matches} \]
How many batteries do we need?

IF no batteries are recharged, how many batteries are required?

• 18 matches / 6 matches/battery = 3 batteries

Not confident – Add a Safety Factor!
3 batteries x 2 = 6 batteries
How long will a battery stay charged?
Cold Battery Capacity?

Store > -15°C
Store > -15°C

How long to warm up a cold battery?
Open Circuit Voltage Does NOT Indicate State of Charge
A National Instruments 9201 module must be installed in slot 1 of the cRIO-FRC. An analog breakout must be connected to this module. A jumper must be installed in the “Power” position (two outer pins) on the analog breakout. The analog breakout must be powered from the PD Panel. These connections enable monitoring of the battery charge by the team and the Field Management System. This is a required element of the ROBOT configuration.
An automatic battery charger rated for a maximum of 6 amperes must be used to charge the supplied batteries. When recharging the KOP batteries, either the charger provided by FIRST or an automatic charger with an equivalent charging current rating may be used.
Charging

**Genesis NP18-12B**
- 14.4 to 15.0 V
- 4.3 A maximum

**MK ES17-12**
- 14.4 to 15.0 V
- 5.4 A maximum
Chargers charge differently!

• Constant voltage (older)
• Constant current (newer)
• Combination (“smart”)

Read the manual!
Constant Current

- 2, 4 or 6 Amps

\[ i = 4 \text{ Amps} \]
\[ Q = 17.1 \text{ Ahrs} \]
\[ Q = i \times t \]
\[ t = \frac{Q}{i} \]
\[ = \frac{17.1}{4} \]
\[ = 4.275 \text{ hours} \]
Constant Voltage

- 14.3 V
- Up to 6 A

\[ Q = 17.1 \text{ Ahrs} \]
\[ Q = i \times t \]
\[ t = \frac{Q}{i} \]
\[ = \frac{17.1}{6} \]
\[ = 2.85 \text{ hours} \]

NOT!
“Smart” Chargers

- Desulphation < 0.5 hours
- Constant current 3.3 A
  \[ Q = 17.1 \text{ Ahrs} \]
  \[ Q = i \times t \]
  \[ t = Q / i \]
  \[ = 17.1 / 3.3 \]
  \[ = 5.2 \text{ hours} \]
- Constant voltage 14.4 A
  \[ = ? \text{ Hours} \]
  \[ = \text{observed} < 2 \text{ hours} \]
- TOTAL = 8 hours
Can we shorten the time by charging 2 batteries in parallel?

No!

Need to charge twice the capacity:
\[ 2 \times Q = 2 \times 17.2 \text{ A-hr} = 34.2 \text{ A-hr} \]

Charge at a constant current
\[ t = \frac{Q}{A} \]
\[ t = \frac{34.2 \text{ A-hr}}{4.0 \text{ A}} = 8.5 \text{ hours} \]

WARNING
If the batteries are not identical, the battery currents will not be the same.
Internal Resistance Changes with Age

**Genesis NP18-12B**
- 10 mΩ

**MK ES17-12**
- 11 mΩ

Team 781 observes 3mΩ (new) to 7mΩ (old)
Unequal current when charging new and aged batteries in parallel

\[ t = \frac{Q}{i} \]

Battery G
\[ i_1 = 2.8 \text{ A} \]
\[ t = \frac{17.1}{2.8} = 6.1 \text{ hr} \]

Battery A
\[ i_2 = 1.2 \text{ A} \]
\[ t = \frac{17.1}{1.2} = 14.3 \text{ hr} \]

Good Battery Charged too long
DON’T DO IT!
Make a Plan – Work the Plan

• Sequence of using your batteries
• Number of matches per battery
• Sufficient time to charge
• Method of tracking battery state of charge
Mechanical Safety

- Lift with knees
- Hold close to your body
- Minimize grip lifts
- Don’t drop it!
When positioned on the ROBOT, the primary battery must be secured so that it will not dislodge should the ROBOT be turned over or placed in any arbitrary orientation.

G. The 120-amp circuit breaker must be quickly accessible from the exterior of the ROBOT.
Electrical Safety

• Never short the terminals
• Insulate the terminals
• Install the Anderson connectors and use the battery plugs
• Use the 120 A circuit breaker
• Inspect
  – Before charging
  – Before discharging
C. The battery terminals and the connecting lugs must be insulated with shrink tubing and/or electrical tape.
Contains sulfuric acid. Avoid contact with skin, eyes or clothing. In event of accident flush with water and call a physician immediately. KEEP OUT OF REACH OF CHILDREN.

DANGER EXPLOSIVE GASES

Cigarettes, flames or sparks could cause battery to explode. Always shield eyes and face from battery. Do not charge or use booster cables or adjust post connections without proper instruction and training. DO NOT REMOVE VENT VALVES.

MADE IN TAIWAN

PROPOSITION 65 WARN

This product contains chemicals known to the State of California to cause cancer, birth defects or other reproductive harm.
A. The battery must be connected to the ROBOT power system through the use of the Anderson Power Products (APP) connector.
B. The APP connector must be attached to the battery with either the copper lugs provided in the KOP or appropriately-rated and sized lug connectors.
D. The main 120-amp circuit breaker must be directly connected to the hot (+) leg of the ROBOT-side APP connector. Only one 120-amp main circuit breaker is allowed. This breaker must not be bypassed.
E. The PD Board must be directly connected to the APP connector and main 120-amp circuit breaker. No other loads may be connected to the main 120-amp circuit breaker.
F. Each primary power connection between the battery and PD Board must be made with #6 AWG (4.11mm) red and black wire or larger.
A. The battery must be connected to the ROBOT power system through the use of the Anderson Power Products (APP) connector.
B. The APP connector must be attached to the battery with either the copper lugs provided in the KOP or appropriately-rated and sized lug connectors.
D. The main 120-amp circuit breaker must be directly connected to the hot (+) leg of the ROBOT-side APP connector. Only one 120-amp main circuit breaker is allowed. This breaker must not be bypassed.
E. The PD Board must be directly connected to the APP connector and main 120-amp circuit breaker. No other loads may be connected to the main 120-amp circuit breaker.
F. Each primary power connection between the battery and PD Board must be made with #6 AWG (4.11mm) red and black wire or larger.
Chemical Safety

The image shows a pH test strip with two different pH ranges displayed: pH 1 to 2 and pH 8 to 9. The test strip is being held over a surface with visible signs of wear or damage, possibly indicative of chemical exposure or corrosion due to chemicals.
Be Prepared
How do you know your battery is sick?

- Charger indicates it’s sulphated.
- Charger indicates it’s charged too soon.
- Charger takes a long time to charge.
- The case is distorted.
- The battery is unusually hot.
- The open-circuit voltage is unusually low or high.
- The on-load voltage is unusually low.
- High self-discharge
- Wouldn’t charge 2A
- Too fast charge 4A
Distortion, Heat Damage
Sulphated Plates
MICHELLE’S RULE
Recharge your batteries as soon as possible after use.
When will your battery die?

**Genesis NP18-12B**
- 100% discharge: 250 cycles
- 50%: 550 cycles
- 30%: 1200 cycles
- 3 to 5 years

**MK ES17-12**
- 100% discharge: 200 cycles
- 80%: 225 cycles
- 50%: 500 cycles
- 3 to 5 years
Disposal

• Hazardous Waste Day
  – Only twice a year; plan for it
  – Volunteer
• Follow the rules
• Assign someone to know the batteries
• Keep a battery log
• Don’t leave batteries in a discharged state
• Don’t charge batteries in parallel
• Develop a plan to use/charge batteries at competition
• Don’t keep sick batteries; dispose of them properly