USER MANUAL

Magnetic Levitation Experiment

Set Up and Configuration

CAPTIVATE. MOTIVATE. GRADUATE.

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This product meets the essential requirements of applicable European Directives as follows:

- 2006/95/EC; Low-Voltage Directive (safety)
- 2004/108/EC; Electromagnetic Compatibility Directive (EMC)

CONTENTS

1 MAGLEV: PRESENTATION

1.1 MAGLEV: System Description

The typical Magnetic Levitation plant, i.e. MAGLEV, is depicted in Figure 1.1, while levitating in air a steel ball within its magnetic field. The MAGLEV can be described by three distinct sections encased in a rectangular enclosure. First, the upper section contains an electromagnet, made of a solenoid coil with a steel core. Second, the middle section consists of an inside chamber where the magnetic ball suspension actually takes place. One of the electromagnet poles faces the top of a black post upon which a one-inch steel ball rests. The ball elevation from the post top is measured using a photo-sensitive sensor embedded in the post. The post is designed in such a way that when the ball rests on top of it, the air gap between the ball's top hemisphere and the electromagnet pole face is 14 mm. The post also provides repeatable initial conditions for control system performance evaluation.
Finally, the bottom section of the MAGLEV apparatus houses the system's conditioning circuitry needed, for example, by the light intensity position sensor. As detailed later in this manual, both offset and gain potentiometers of the ball position sensor are readily available for proper calibration. A current sense resistor is also included in the design in order to provide for coil current measurement if necessary.

Figure 1.1: MAGLEV Plant

1.2 MAGLEV: Control Challenge

As illustrated in Figure 1.1, above, the purpose of the magnetic levitation experiment is to design a control system that levitates a one-inch solid steel ball in air from the post using an electromagnet. The controller can then track the ball position to a desired trajectory.

The system is supplied with a feedback controller tuned through pole placement but, of course, you may design any other controller you wish. The complete mathematical modeling and system parameters are provided to streamline the implementation of the control theory of your choice.

⚠ **Caution: This equipment is designed to be used for educational and research purposes and is not intended for use by the general public. The user is responsible to ensure that the equipment will be used by technically qualified personnel only.**

2 MAGLEV COMPONENT DESCRIPTION

2.1 Component Nomenclature

As a quick nomenclature, Table 2.1, below, provides a list of all the principal elements composing the MAGLEV Specialty system. Every element is located and identified, through a unique identification (ID) number, on the MAGLEV plant represented in Figure 2.1a and Figure 2.1b, below.

ID	Component	ID	Component
1	MAGLEV Overall Enclosure	7	Position Sensor Offset Potentiometerl
2	Solenoid Coil	8	Position Sensor Gain Potentiometer
3	Coil Steel Core	9	Coil Leads 4-Pin DIN Connector
4	Pedestal and Position Sensor	10	Position Sensor Cable 6-Pin-Mini-DIN Connector
5	Solid Stainless Steel Ball	11	Current Sensor Cable 6-Pin-Mini-DIN Connectorr
6	Interior Lights	12	Inside Chamber

Table 2.1: MAGLEV Component Nomenclature

2.2 Component Description

2.2.1 Overall Enclosure (Component #1)

The MAGLEV overall enclosure is made of aluminum. Its external dimensions are shown in Table 2.2, below.

Description	Value	Unit
Overall Enclosure Height	0.277	m
Overall Enclosure Width	0.153	m
Overall Enclosure Depth	0.153	m

Table 2.2: MAGLEV Overall Dimensions

2.2.2 Electomagnet (Component #2)

The electromagnet consists of a tightly wound solenoid coil made of 2450 turns of 20 AWG magnet wire. For safe operation, it results that the coil continuous current should never exceed 3 A. The coil inductance, resistance, dimensions, and other specifications are shown in Table 2.2. Moreover, the electromagnet wiring, together with the current sense resistor, can be seen in Figure 2.2, below.

⚠ **Caution:** Electromagnet Coil Input Voltage: $\pm$24 V, 3 A peak.

2.2.3 Light Sensor (Component #4)

The light-sensitive sensor measuring the steel ball vertical position consists of a NPN silicon photodarlington. The position sensor is embedded inside the ball pedestal and provides linear position readings over the complete ball vertical travel. Its output measurement is processed through a signal conditioning board and made available as 0 to 5V DC signal. Its measurement sensitivity is given in Table 3.1, below.

(a) Front View (b) Back View

Figure 2.1: MAGLEV Plant

⚠ **Caution:** It is to be noted that the phototransistor measurement is sensitive to its environmental light conditions. To that effect, two lights represented by components #6 in Figure 2.1a are present in the chamber interior to provide repeatable and constant light conditions. However, as detailed in a following section, **a calibration of the sensor offset and gain potentiometers (components # 7 and 8, respectively) is required to keep consistent measurements in changing light environments.** As a consequence, the user should also avoid disturbing the light conditions inside the MAGLEV chamber by, for example, grasping the ball with his/her whole hand inside chamber.

2.3 MAGLEV System Wiring Schematic

The schematic depicted in Figure 2.2, below, presents a wiring diagram of the MAGLEV cable connectors in association with the system electrical components, namely, the electromagnet coil, current sense resistor, interior lights, and photodarlington.

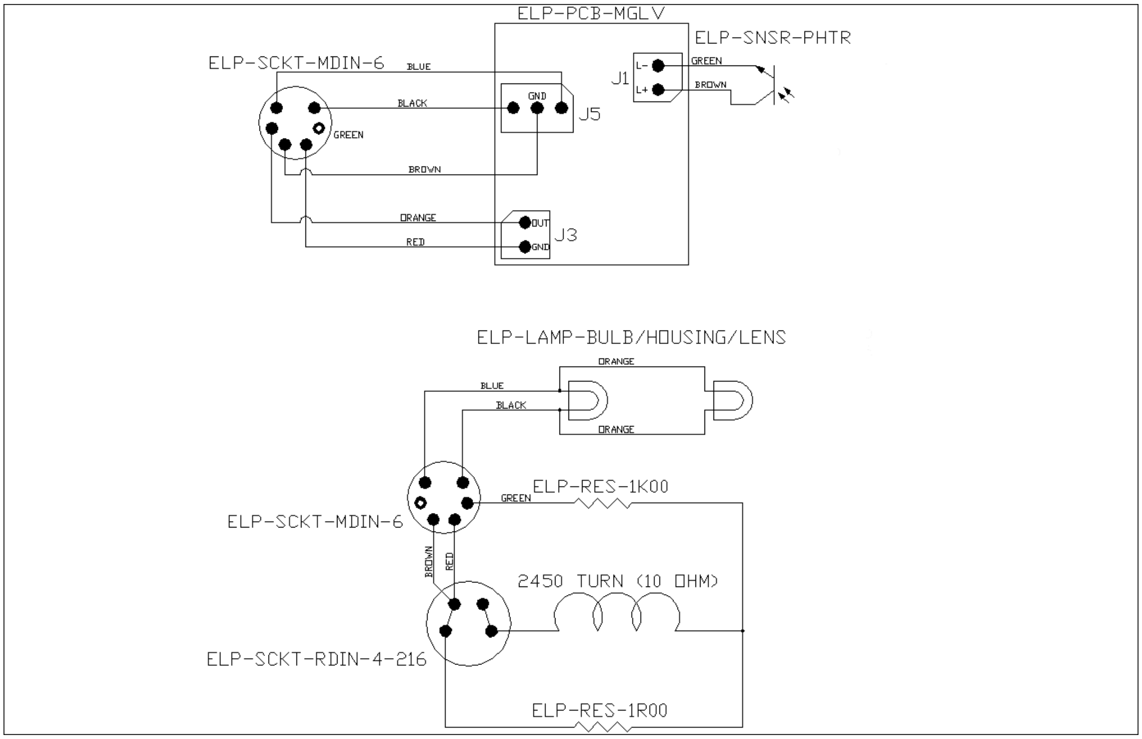


Figure 2.2: MAGLEV System Wiring Schematic

3 MAGLEV MODEL PARAMETERS

Table 3.1 lists and characterizes the main parameters (e.g. mechanical and electrical specifications, convertion factors, constants) associated with the MAGLEV specialty plant. Some of these parameters can be used for mathematical modeling of the MAGLEV system as well as to obtain the steel ball's Equation Of Motion (EOM).

Symbol	Description	Value	Unit
c_{max}	Maximum Continuous Coil Current	3.0	$\pm$ A
L_c	Coil Inductance	412.5	mH
R_c	Coil Resistance	10	Ω
N_c	Number Of Turns in the Coil Wire	2450	
l_c	Coil Length	0.0825	m
r_c	Coil Steel Core Radius	0.008	m
K_m	Electromagnet Force Constant	6.5308×10^{-5}	$N - m^2/A^2$
Rs	Current Sense Resistance	1	Ω
r_b	Steel Ball Radius	1.27×10^{-2}	m
M_b	Steel Ball Mass	0.068	kg
T_b	Steel Ball Travel	0.014	m
g	Gravitational Constant on Earth	9.81	m/s^2
μ_o	Magnetic Permeability Constant	$4\pi \times 10^{-7}$	H/m
K_B	Ball Position Sensor Sensitivity (Assuming a User-Calibrated Sensor Measurement Range from 0 to 5 V)	2.83×10^{-3}	m/V

Table 3.1: MAGLEV System Model Parameters

4 WIRING PROCEDURE FOR THE MAGLEV

This section describes the standard wiring procedure for the MAGLEV specialty plant. The following hardware, accompanying the MAGLEV, is assumed:

1. **Power Amplifier**: Quanser VoltPAQ-X1, or equivalent
2. **Data Acquisition Board**: Quanser Q1-cRIO, Q2-USB, Q8-USB, QPID/QPIDe, NI DAQ, or equivalent.

For detailed information regarding the Quanser VoltPAQ amplifier unit please refer to [2] and for information on the DAQ please refer to [1]

⚠ **Caution:** When using the Quanser VoltPAQ-X1 power amplifier, **make sure you set the *Gain* to 3**!

⚠ **Caution:** The MAGLEV plant is to be used with Quanser provided amplifier units only. Use caution if you are using a different amplifier unit than the one provided by Quanser.

⚠ **Caution:** If the equipment is used in a manner not specified by the manufacturer, the protection provided by the equipment may be impaired.

⚠ **Caution:** Do not position the equipment so that it is difficult to operate the on/off switch on the power amplifier.

⚠ **Caution:** The coil can get hot after use.

⚠ **Caution:** Magnetic field present around the experimental hardware when in use.

⚠ **Caution:** Perform all the wiring steps with the amplifier and your PC both turned off.

4.1 Cable Nomenclature

Table 4.1, below, provides a description of the standard cables used in the wiring of the MAGLEV.

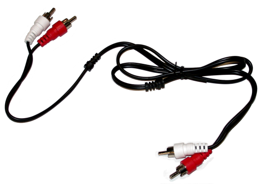
Cable	Designation	Description
 (a) RCA Cable	2xRCA to 2xRCA	This cable connects an analog output of the Data Acquisition (DAQ) Device to the power module for proper power amplification.
 (b) "To Load" Cable	4-pin-DIN to 6-pin-DIN	This cable connects the output of the power module, after amplification, to the desired actuator (e.g. electromagnet).
 (c) Analog Cable	6-pin-mini-DIN to 6-pin-mini-DIN	This cable carries analog signals from one or two plant sensors to the amplifier, where the signals can be either monitored and/or used by an analog controller The cable also carries a $\pm$ 12 VDC line from the amplifier in order to power a sensor and/or signal conditioning circuitry.
 (d) 5-pin-DIN to 4xRCA	5-pin-DIN to 4xRCA	This cable carries the analog signals, previously taken from the plant sensors, unchanged, from the amplifier to the Digital-To-Analog input channels on the Data Acquisition (DAQ) Device.

Table 4.1: Cable Nomenclature

4.2 Typical Connections for the MAGLEV System

The connections between the MAGLEV plant, the data acquisition board, and the amplifier is depicted in Figure 4.1

The MAGLEV system contains two feedback sensors. One is a small current sense resistor in series with the coil. The other is a photodarlington embedded in the chamber pedestal and providing the ball position signal. Both current sensor and photodarlington are wired to one 6-pin-mini-DIN socket each, as seen in the wiring schematic in Figure 2.2. Pictures of the same 6-pin-mini-DIN socket are available in Figure 2.1b, where they are represented as components #11 and #10, respectively. To connect these two analog sensors and the electromagnet, follow the steps described below:

1. **Connect the "Amplifier Command" Cable - Cable #1:**
   The "Amplifier Command" cable is the 2xRCA to 2xRCA cable described in Table 4.1 and shown in Figure

4.1a. Connect one RCA end of this cable to the **Analog Output 0 (i.e. AO # 0)** of your Data Acquisition (DAQ) Device and the other corresponding RCA connector to the socket labelled **"Amplifier Command"** on the amplifier. This connection is illustrated by cable #1 in Figure 4.1.

2. **Connect the "To Load" Cable - Cable #2:**
   The "To Load" 4-pin-DIN-to-6-pin-DIN cable described in Table 4.1 and shown in Figure 4.1b. First, connect the cable 4-pin-DIN connector to the MAGLEV **Coil Connector**, which is shown as component #9 in Figure 2.1b. Then connect the cable 6-pin-DIN connector to the amplifier socket labelled **"To Load"**. The connection to the amplifier is illustrated by cable # 2 in Figure 4.1, below.

3. **Connect the "To Analog-To-Digital" Cable - Cable #3:**
   3. The "To Analog-To-Digital" cable is the 5-pin-DIN-to-4xRCA cable described in Table 4.1 and shown in Figure 4.1d. First, connect the cable 5-pin-DIN connector to the amplifier socket labelled **"To ADC"**, as illustrated by cable #3 in Figure 4.1, below. The other end of the cable is split into four RCA connectors, each one labelled with a single digit ranging from one to four. This numbering corresponds to the four possible analog sensor signals passing through the amplifier , namely S1, S2, S3 and S4. In order for the analog signals to be used in software, you should then connect yellow socket of the RCA cable to Analog Input 0 and red socket of the RCA cable to Analog Input 1. Specifically, connect **S1 to Analog Input 0 and S3 to Analog Input 1** as illustrated by cable #3 in Figure 4.1, below.

4. **Connect the "From Analog Sensors" Cable - Cable #4:**
   1. The "From Analog Sensors" cable is the 6-pin-mini-DIN-to-6-pin-mini-DIN cable described in Table 4.1 and shown in Figure 4.1c. First connect one end of the cable to the **Sensor Connector**, located at the back of the MAGLEV and which is shown as component #10 in Figure 2.1b. Then connect the cable's other end to the amplifier socket labelled **"S1 & S2"**, which is contained inside the amplifier "From Analog Sensors" front panel. These connections are illustrated by cable #4 in Figure 4.1.

5. **Connect the "From Analog Sensors" Cable - Cable #5:**
   2. The "From Analog Sensors" cable is the 6-pin-mini-DIN-to-6-pin-mini-DIN cable described in Table 4.1 and shown in Figure 4.1c. First connect one end of the cable to the Current Sense Connector, located at the back of the MAGLEV and which is shown as component #11 in Figure 2.1b. Then connect the cable's other end to the amplifier socket labelled "S3", which is contained inside the amplifier "From Analog Sensors" front panel. These connections are illustrated by cable #5 in Figure 4.1.

In other words, the ball position is sensed using Analog Input (AI) #0 through the amplifier analog channel S1, and the coil current is sensed using Analog Input (AI) #1 through the amplifier analog channel S3.

⚠ **Caution: If the equipment is used in a manner not specified by the manufacturer, the protection provided by the equipment may be impaired.**

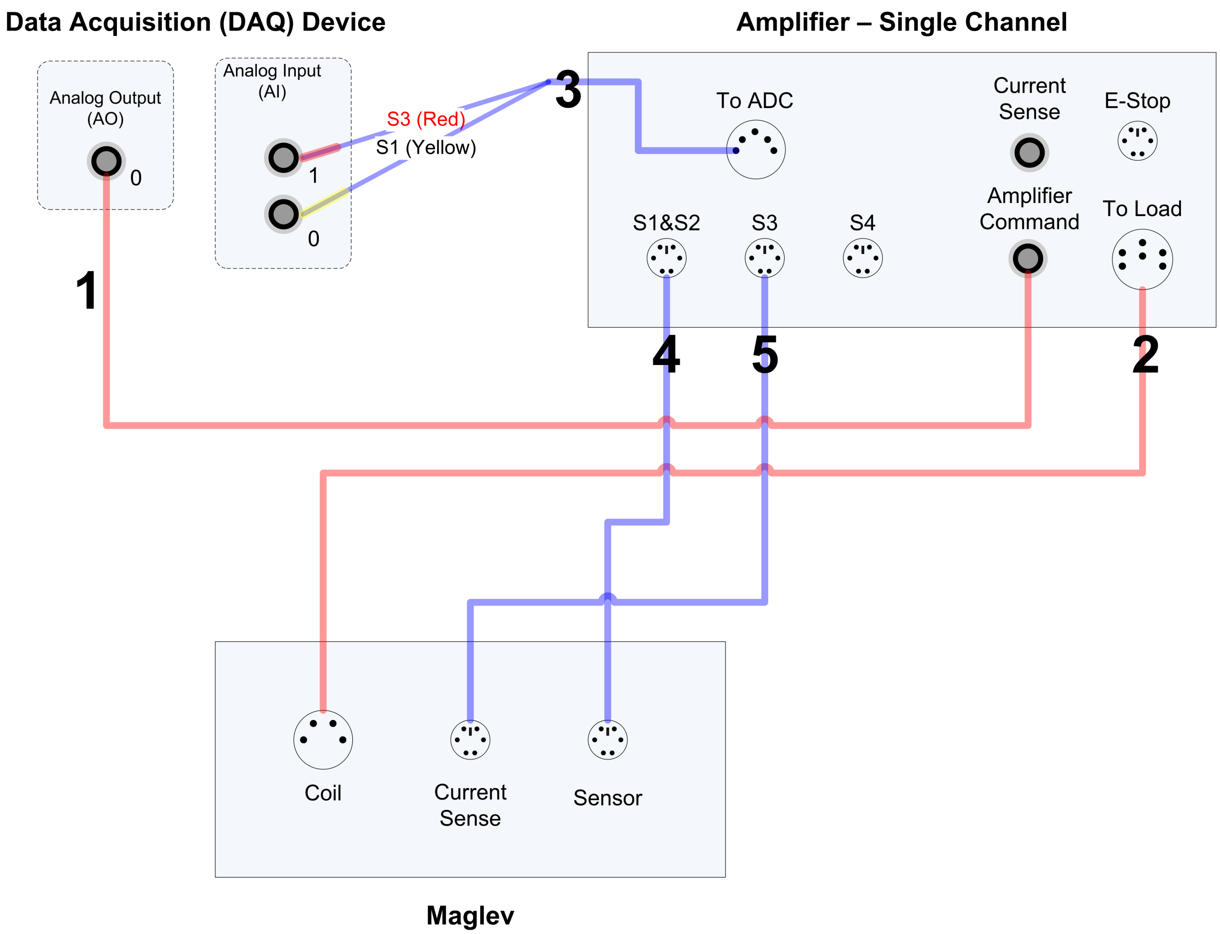


Figure 4.1: MAGLEV connections to amplifier and data-acquisition board

4.3 MAGLEV Wiring Summary

Cable	From	To	Signal
1	Data Acquisition (DAQ) Device: Analog Output #0	Amplifier **Amplifier Command** connector	Control signal to the amplifier.
2	Amplifier: **To Load** connector	MAGLEV **"Coil"** connector	Power leads to the coil.
3	Amplifier: **To ADC** connector	Data Acquisition (DAQ) Device: • S1 (Yellow)to Analog Input **#0** • S3(Red) to Analog Input **#1**	Position and current feedback signals to the Data Acquisition (DAQ) Device, through the amplifier.
4	MAGLEV **"Sensor"** connector	Amplifier **"S1 & S2"** connector	Position feedback signal to the amplifier.
5	MAGLEV **"Current"** connector	Amplifier **"S3"**	Current feedback signal to the amplifier.

Table 4.2: MAGLEV Wiring Summary

5 BALL POSITION SENSOR CALIBRATION

The photosensitive ball position sensor is calibrated at the factory but may need re-adjustment when you receive it, or under changing external light conditions.

The position voltage measured on the amplifier channel S1 should be zero when the ball is resting on the black post, while it should be between 4.75 Volts and 5 Volts when the ball is held up by (or stuck to) the electromagnet. Such a procedure results in a precisely known conversion factor relating ball displacement to sensor output voltage.

5.1 Calibration Procedure

The calibration procedure detailed in the following subsections is to calibrate the two potentiometers, namely "Offset" and "Gain", shown in Figure 2.1a, above, as components #7 and #8, respectively. The Offset and Gain potentiometers are part of the signal conditioning circuitry of the photodarlington used as a position sensor for the steel ball.

In order to run the calibration procedure, first ensure that the MAGLEV system is wired as previously described. Then power up the amplifier. The two lights inside the chamber should go on. The calibration should be carried out under normal external light conditions at the location where you are planning to use the apparatus. You may also use a level to level the MAGLEV rig, so that both electromagnet axis and gravity force acting on the steel ball are aligned. You are now ready to proceed.

5.1.1 Zero "Offset" Potentiometer Calibration: At Voltage Zero

Follow the steps below to calibrate the **Offset** Potentiometer, #7 in Figure 2.1a, above.

1. If it is not yet present, place the steel ball on the post inside the MAGLEV chamber.
2. Run the supplied calibration software files.
3. Set the electromagnet current to 0.0 A, the ball continues resting on the post.
4. This current can be monitored in the Ic (A) display found in the calibration software.
5. Using a potentiometer adjustment tool (i.e. a small flat-end screwdriver), manually adjust the **offset** potentiometer screw on the MAGLEV enclosure to obtain zero Volts on the Vb (V) display. Turning the offset potentiometer screw clockwise increases the voltage Vb, and vice-versa.
6. Once a value of zero is obtained for Vb, stop the calibration software by clicking on the "Stop" button.

5.1.2 "Gain" Potentiometer Calibration: At The Maximum Voltage

Follow the steps below to calibrate the **Gain** Potentiometer, #8 in Figure 2.1a, above.

1. If it is not yet present, place the steel ball on the post inside the MAGLEV chamber.
2. Run the supplied calibration software files.
3. Set the electromagnet current to 2.0 A. This should cause the steel ball to jump up to the electromagnet core face and stay there, attaining the other limit of its displacement range. If the ball does not jump up, you can give it a small lift. You can now calibrate the gain potentiometer if necessary.

4. Using a potentiometer adjustment tool (i.e. a small flat-end screwdriver), manually adjust the gain potentiometer screw on the MAGLEV enclosure to obtain anywhere **between 4.75 and 5 Volts** on Vb. Turning the potentiometer screw counter-clockwise increases the voltage Vb, and vice-versa.

5. Once you are done with the calibration process, stop the calibration software by clicking on the "Stop" button.

6 TROUBLESHOOTING

Please review the following before contacting Quanser's technical support.

1. Review the connection outlined in Section 4.2 in this manual.
2. Make sure cables are firmly connected.

6.1 Ball is not levitating.

1. Review Connection of cables #1 and #2 in Figure 4.1.
2. Ensure the power amplifier is powered on and operational, e.g., when using VoltPAQ verify that the green LED is lit.
3. If using the VoltPAQ-series amplifier, make sure the Gain switch is set to 3.
4. Verify the data acquisition device is functional.
5. Ball or current may not be reading properly. See troubleshooting step below.

6.2 Ball position sensor or current sensor is not reading.

1. Review Connection of cables #3, #4, and #5 in Figure 4.1.
2. Ensure the power amplifier is powered on and operational, e.g., when using VoltPAQ-X1 verify that the green LED is lit.
3. Verify that the data acquisition (DAQ) board is functional. Go through the DAQ User Manual for troubleshooting guidelines.

6.3 Ball is not stabilizing when software is running

1. Make sure the inside chamber of the MAGLEV is not be exposed to any bright light.
2. Re-calibrate the MAGLEV as dictated in Section 5.

7 TECHNICAL SUPPORT

To obtain support from Quanser, go to http://www.quanser.com/ and click on the Tech Support link. Fill in the form with all the requested software and hardware information as well as a description of the problem encountered. Also, make sure your e-mail address and telephone number are included. Submit the form and a technical support person will contact you.

REFERENCES

[1] Quanser Inc. *Q2-USB Data-Acquisition System User's Guide*, 2010.

[2] Quanser Inc. *VoltPAQ User Guide*, 2010.

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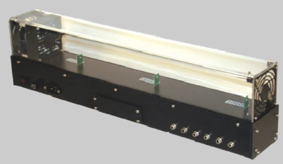
Magnetic Levitation

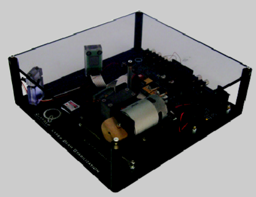
Heatflow Experiment



Coupled Tank

Solar Tracker

Laser Beam Stabilizer



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