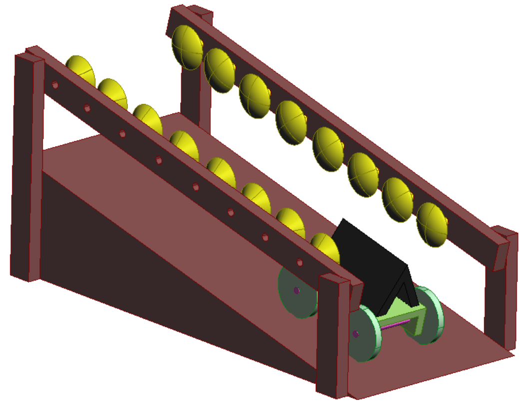
EN4 Dynamics and Vibrations

Design Project

Design and construction of a solar powered vehicle



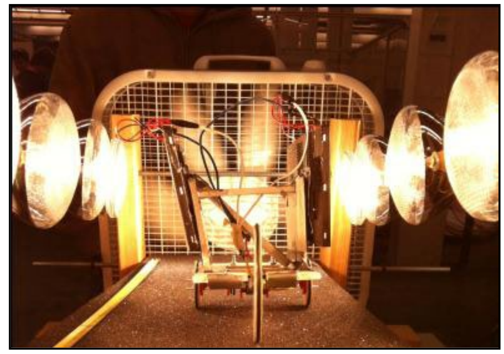
Synopsis

In this project you will design and construct a small solar powered vehicle to climb a ramp at the maximum possible speed.

1. Organization

- You may work on this project in groups of up to five.
- The project 'deliverables'; are (i) An assembled and tested vehicle; (ii) A report (one report per group) describing your design, and describing the calculations you used to design it; (iii) a short oral presentation describing your design and design procedures; and (iv) an evaluation of the performance of your team-mates on the project.
- Materials for building your vehicle can be found in room 222A in Brown Design Workshop. Some parts will be provided as a kit. You can pick up your kit between 9am and noon on Wed April 27 from room 157 B&H (if you need it early, eg if you plan to 3D print parts), or from 222a BDW during hours that TAs or faculty are supervising.
- Workshop facilities for building your vehicle will be open between Mon May 2 and Thurs May 5. TA & faculty hours will be advertised on the announcements page of the website.
- Teams will demonstrate their design to faculty or TAs on Friday May 6. As part of the testing, they will give a short (10 min) presentation describing their design procedure. Written reports are due at the presentation.
- **Optional:** If you wish, you may 3D print parts for your vehicle. If you wish to do so, please upload STL files to CANVAS as early as possible, and no later than noon May 2, to leave time to print the parts. See **Appendix B** for more information about 3D printing.
- **Warning:** We only have 4 ramps with light bars to test vehicles. Your team will be able to work much more efficiently if you come to the workshop at less crowded times – the lab is usually fairly empty early in the week, and during the 9am and lunchtime timeslots. It will also make construction much easier for everyone if you can help by returning unused tools and materials once you are done with them – this will help minimize the time people need to spend hunting around for tools and supplies. Finally, while we keep the workshop open during evening hours, we can't do things like replenish supplies in the evenings when the stockroom is closed and technician help is not available. It is also difficult for us to handle a last-minute rush the day before the project is due, so it is helpful if you can start early.

2. Overview of design requirements



The goal of this project is to design and construct a small solar-powered vehicle that will climb a ramp at the maximum possible speed, using materials and supplies supplied for this purpose.

The ramp is 48” long and 12” wide. The slope varies between 0 and 17.5 degrees in 2.5 degree increments. A bank of incandescent light-bulbs on each side of the ramp provides a (poor) substitute for sunlight. The distance between the light banks on the two sides of the ramp can be adjusted to accommodate different vehicle widths, but the distance between them can’t exceed 12”.

A detailed list of materials and supplies can be found in Appendix B. Supplies include

1. A set of four 3V, 200mA solar modules. These will be connected together in parallel.
2. A brushed DC permanent magnet motor; with a built-in gearbox that can be modified to provide different transmission ratios (the ratios are listed in the spec sheet in the Appendix). The default motor is the 12 speed Tamiya model, but the pandemic has affected the supply chain for this part so we have a backup motor in case we run out (eg if a lot of motors get broken)
3. A set of wheels with various diameters;
4. Hardware that can be used to construct a chassis.

The solar panels must be carried by your vehicle – you can’t save weight by attaching the panels to the vehicles using wires. The solar panels and motor must also be the sole power source for your vehicle.
To complete the design, you will need to:

(i) Design a power transmission system that will ensure that the car climbs the slope at maximum speed;
(ii) Assemble and test the vehicle.
(iii) Document your design calculations and design specification in a report (one per group).

There are four particularly important design considerations:

1. The transmission and wheels must be designed to extract the maximum power from the solar panels and electric motor;
2. The total weight of the vehicle must be minimized;
3. Friction losses must be avoided as far as possible;
4. You need to place the solar panels as close to the light source as possible – **but not so close that they will melt – the panels must be at least 4” away from the lights** (and since the spots illuminate a relatively small area, try to design the system so that a few panels remain close to the spotlight as the vehicle moves past the light-bank)

This project description provides all the information you need to design the transmission system.

3. Design calculations

The goal of the calculation is to predict how long your vehicle takes to travel (from rest) a known distance L up a ramp with slope θ. The time depends on the gear ratio in the car’s transmission, and the diameter of the driving wheels (as well as on the amount of light energy available). You can use the calculation to predict the optimal gear ratio and/or wheel diameter for your vehicle. The calculation involves 6 steps:

(1) Find the values of two constants that describe the properties of the solar panel (see appendix A1)
(2) Find the values of the constants in the equations that describe the motor (see appendix A2).

(3) Plot the power-curve and torque-curve for the solar panel – motor system (the power/torque curve are plots of the power and torque as a function of the angular speed of the motor)
(4) Use rigid body kinematics formulas to predict how the car's speed depends on the angular speed of the motor (in terms of the wheel radius and the gear ratio).
(5) Derive the differential equation of motion for the vehicle (to predict its speed and distance traveled as a function of time);
(6) Write a MATLAB script that will solve the equation of motion, and predict how long it takes the vehicle to reach the end of the ramp. You can use this script to select the gear ratio and wheel radius that will minimize the time.

The steps in this process are described in more detail below.

3.1 Plotting the power-curve for the motor-panel combination

1. You will need to find values for the constants I_0 and *n* in equations relating the current *I* and voltage *V* out of the solar panels (all the other constants are known, and are listed in Appendix A1). These will vary, depending on the amount of illumination available, so you will need to measure them. To do this, you can measure the current-voltage relation for your panels using the electronic loads provided in BDW). Then, you can choose the values of I_0 and *n* that best fit the experimental data. But for preliminary calculations, you can assume that a single panel has $I_0 = 0.2A$ and *n=16*. (Your car will have four panels connected together in parallel, which multiplies the total current out of the panels by 4, but does not change *n*).
2. Next, find values for the parameters characterizing the electric motor. You will need to determine values for the parameters β, R, T_0, τ_0 in the motor equations (2) and (3) , from the values for the stall current, and the stall torque, no-load speed and no-load current (the video tutorial explains in more detail how to do this). You can measure some of the data you need for your actual motor, but the table below gives values you can use for preliminary calculations. Be very careful to convert everything to SI units.

Table 1: Approximate properties of motor/gearboxes

	Tamiya motor/gearbox (default motor)	913D motor/gearbox (for backup only)
Operating voltage *V*	3V	3V
No load current	60 mA	0.3A
No load speed	8400 rpm	14800 rpm
Stall current	0.6A	2.8A
Stall torque	$1.76\text{x}10^{-3}$Nm†	$4.802\text{x}10^{-3}$Nm

3. To plot the torque curve (a plot of torque-v-angular speed of the motor), note that (a) Given a voltage *V*, you can use the solar panel equation (1) in Appendix A1 to calculate the current *I* from your four solar panels (multiply the total current by 4, not just I_0). Then you can use the first motor equation (2) in Appendix A2 to find the motor speed, and the second motor equation (3) to find the torque. This lets you do a parametric plot, varying *V* between 0 and about 3.5*V*, and then plot ω on the horizontal axis and *T* on the vertical axis. You can do this in MATLAB, or Excel if you prefer. To plot the power curve, repeat the procedure but plot power $P = T_m \omega$ instead of torque.

† Estimated – you can measure this for your motor. See Sect 4.

The power curve will give you an idea of what speed the motor needs to run at to extract the maximum power from your panel/motor combination. On high slopes (above about 10 degrees), the car will reach its terminal speed quickly enough to run at the optimal power for most of the way up the ramp. But on lower slopes, the car will continue to accelerate all the way up the ramp. So, to design the optimal vehicle on the full range of possible slopes, you will need to analyze the motion of the car as it accelerates. Section 3.4 describes how to do this.

3.2 Correcting for friction losses

Energy is lost to friction in

(1) The gearbox, which accounts for the majority of lost energy. Since the forces in the gearbox is proportional to the torque transmitted, the lost power is proportional to the transmitted power. The power out of the gearbox is related to the power supplied by the motor (approximately) by

$$P_{out} = \eta P_{in}$$

where η is the gearbox efficiency. The value of η will need to be measured. For preliminary calculations, take $\eta = 0.2$. You will find that the efficiency depends on the gear ratio. Smaller gear ratios usually have a better efficiency, because fewer gears are used.

(2) A smaller amount of energy is lost to friction in the axles, rolling friction, and air resistance. These both depend on the speed of the vehicle. We can use

$$P_{lost} = C_R v + C_D v^2$$

where C_R, C_D are two constants, which you will need to measure. For preliminary calculations you can assume $C_R = C_D = 0$. You may find that it is impossible to measure C_D - if so, just assume it is zero.

3.3 Calculating the transmission ratio

The transmission ratio is the ratio of the angular speed of the motor to the car speed $r = \omega_m / v$. To calculate the transmission ratio

(1) Use the rolling wheel formula to write down the angular speed of the car's drive axle as a function of its speed *v* and the wheel radius *R*

(2) Multiply the angular speed of the axle by the gear ratio $\rho = \omega_m / \omega_{axle}$.

3.4 Calculating the car's acceleration

To calculate the time for the car to reach the end of the ramp, we need a procedure to calculate its acceleration. Note that we won't be able to get an explicit formula for the acceleration, because the current (and voltage) of the solar panel can only be calculated by solving a nonlinear equation numerically.

We can use the energy equation for a particle to find a formula for the acceleration of the vehicle. Assume that the panels, motor, and gearbox produce a useful power $P = \eta T_m \omega_m$, where $T_m(\omega_m)$ is the output torque from the motor (which is a function of motor speed); and $\eta \approx 0.2$ is the efficiency. The power must equal the rate of change of kinetic and potential energy, and the power lost to axle friction and air drag, so that

$$P = \eta T_m \omega_m = \frac{d}{dt}\left\{\frac{1}{2}mv^2 + mgh\right\} + C_R v + C_D v^2$$

where m is the car's mass, and h is its height above some convenient datum. Evaluating the time derivative, noting that $dh/dt = v\sin\theta$ and rearranging, we get a differential equation for v. It is also helpful to solve for the distance traveled, so you can add an 'event' function that will stop the calculation when the car reaches the end of the ramp. In MATLAB form the equations become

$$\frac{d}{dt}\begin{bmatrix} x \\ v \end{bmatrix} = \begin{bmatrix} v \\ \frac{1}{m}\left\{\frac{\eta T_m \omega_m}{v} - mg\sin\theta - C_R - C_D v\right\} \end{bmatrix}$$

The torque $T_m(\omega_m)$ varies with the speed of the vehicle, and (for a given vehicle speed) can be calculated as follows:

(i) Calculate the motor speed $\omega_m = rv$, where r is the transmission ratio calculated in 3.3 (you will have to choose a wheel radius and gearbox ratio to get a number for r). Note also that $\eta T_m \omega_m / v = \eta T_m r$ so there won't be a division by zero when the car is stationary.

(ii) Eliminate the motor voltage from the motor equation and panel equation (see Appendices)

$$I_m = (V - \beta\omega_m)/R \qquad\qquad I = I_0 - I_1(e^{qV/nkT} - 1)$$

Here, $I_m = 4I$ is the current flowing through the motor (the factor of 4 is because you have 4 panels in parallel); V is the voltage across the motor terminals; β, R are constants characterizing the motor; and I_0, I_1, q, n, k, T are the constants for a single solar panel. This gives a nonlinear equation

$$I_0 - I - I_1\left(\exp\left[\frac{q(4IR + \beta\omega_m)}{nkT}\right] - 1\right) = 0$$

that can be solved for I. You will need to use the MATLAB 'fzero' function for this purpose. You can find instructions for 'fzero' in the Matlab tutorial. Briefly:

- Write a function of the form
```
function z = f(II,I0,I1,n,k,T,q,R,beta,omegam)
```
  that will calculate a value for

$$z = I_0 - I - I_1\left(\exp\left[\frac{q(4IR + \beta\omega_m)}{nkT}\right] - 1\right)$$

- Solve the equation by using
```
current = fzero(@(II) f(II,I0,I1,n,k,T,q,R,beta,omegam),0.2);
```

It is a good idea to write the code to solve this equation and test it before starting to code your ODE solver. When you write your code to solve the differential equations, the 'fzero' call will need to be inside your 'differential equation' function (which calculates the time derivatives of [x,v])

(iii) The motor torque can then be calculated using the second motor equation

$$T_m = \begin{cases} \beta I_m - T_0 - \tau_0\omega_m & I_m > T_0/\beta \\ 0 & I_m < T_0/\beta \end{cases}$$

3.5 Calculating the time to reach the end of the ramp

The time for the vehicle to reach the end of the ramp can be calculated by solving the equations of motion for the position and speed of the car.

To set up the calculation in MATLAB, you can write the differential equations for the distance traveled and vehicle speed using ode45 in the usual way. To calculate the time required to reach the end of the ramp, you can use an 'event' function to stop the calculation when $x=L$.

For your preliminary calculations, choose some sensible values for the wheel diameter and gear ratio (see the motor/gearbox specifications for available values).

Check your calculations by plotting the speed of the vehicle as a function of time, and make sure the plots look sensible. You can experiment with the effects of changing the slope, gear ratio and wheel diameter. For a given slope, there will be an optimal value for r that minimizes the time to reach the end of the ramp. For high slopes (above 10 degrees) the vehicle should travel at constant speed for most of the distance. With the optimal value of r, the motor will be running at its maximum power point.

The easiest way to optimize r will be to plot a graph of time as a function of r. Then select a wheel radius and gear ratio that gives you a transmission ratio close to the optimum value.

4. Testing your vehicle and components

Here are some tests you can run to try to get more accurate values for the properties of your vehicle. You can do some, all, or none of these, or come up with your own experiments. You do get a few points of credit for doing some experiments though….

1. You can measure the *I-V* curve for the solar panels using the electronic loads provided. The *I-V* curve depends on the distance of the panels from the lights; the power produced by the panels also drops as they heat up. **If you try this experiment be careful not to melt the panels.**
2. You can measure the no-load speed and no-load current of your motor by putting a small number of gears in the gearbox; attaching a wheel to the output shaft so you can count the number of revolutions easily, connecting a power supply to the motor, and running it (with no load) to measure the angular speed of the wheel. You can calculate the motor speed using the known gear ratio.
3. You can measure the value of the static friction torque T_0 for your motor directly, by connecting the motor to a power-supply, turning down the voltage until the motor is just barely turning, and measuring the current. The known value of β then allows you to determine the torque. Once you know T_0 you can calculate the stall torque, but you don't really need it, since your design calculations only need a value for T_0.
4. You can measure the stall current by attaching some gears; putting a wheel on the output shaft, and connecting the motor to a power supply. Set a lower voltage on the supply than $3V$ to avoid damaging your gears/motor (eg $1.5V$), then hold the wheel to prevent it from turning, and record the current. You can use this measurement to determine the winding resistance R, and hence determine the stall current at $3V$.
5. For the Tamiya motor/gearbox, the manufacturer quotes the maximum (stall) torque available from the output shaft of the gearbox for each gear ratio. You can use this data, together with your measured value for the static friction torque T_0 from experiment (2), to determine the efficiency η of the gearbox (you will get a different value for each gear ratio). You should be able to show that the

efficiency is $\eta = T_{Spec} / (\rho[\beta I_s - T_0])$, where I_s is the stall current (at 3V, not the value you measured in step 3), $\rho = \omega_{motor} / \omega_{axle}$ is the gear ratio, and T_{spec} is the output torque value listed in the manufacturer's table.

6. Finally, you can try to estimate values for the coefficients C_R, C_D that govern losses in the vehicle by measuring its steady-state speed (i.e. after the initial acceleration). You can then determine the power supplied by the motor using the power-curve for the motor-panel combination. Correcting the power for the gearbox efficiency will tell you the power loss. Note that the value of C_R is likely to depend on the ramp slope. If you are able to measure the power for several speeds, you can determine both C_R, C_D, but it may be too difficult to get consistent data out of these experiments. If so, it should be sufficient to assume $C_D = 0$ and get the best value you can for C_R.

5. Report Guidelines

Your report should describe your design, and outline the calculations and experiments that you used to select critical parameters in the design.

Here is a possible outline for the report:

1. Executive Summary - a short description of the purpose of the report; an outline of its contents; and a short summary of the conclusions (eg a statement of the expected performance of the vehicle)
2. Operating instructions – a short description of how to choose the correct wheel diameter and gear ratio given the ramp slope (this could be presented in tabular or graphical form, or you could give users an app that does the prediction)
3. Design Specifications – a description of your design, highlighting special features and giving details of important design parameters (e.g. the total weight of the vehicle, and its transmission ratio, its expected performance, etc).
4. Design Calculations – describe the procedure you used to determine the transmission ratio and any other critical design parameters.
5. Experimental measurements – describe any tests you ran to help determine properties of your motor, gearbox, panels and vehicle; or tests you ran to measure the vehicle's performance (which could be compared to predictions)

6. Grading Rubric

Your project will be graded as follows:

Successfully built and tested vehicle: (10 points)
Design Calculations (10 points)
Measurements and testing motor/panels/vehicle (5 points)
Oral presentation: (5 points)
Project Report (10 points)
Peer Evaluation (5 points)
Returning hardware kit (especially wheels, motor, and panels): (5 points)

(50 Points)

Appendix A: Solar panel and motor equations

A1 Characteristics of solar panels

You can read a short summary of the features and operating principles of solar cells at http://zone.ni.com/devzone/cda/epd/p/id/5918. Here, we summarize the information that you will need to design your vehicle.

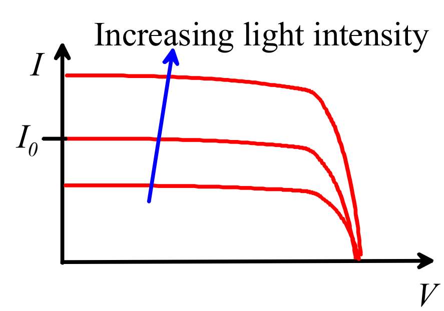
A photovoltaic cell is a semiconductor device that converts incident radiation into electrical current. Cells are usually connected together into a *module* or *array* of cells, to increase their electrical power output. You will be provided with four such modules, connected together in parallel. Each module is advertised as generating a nominal current of 200 mA under `1 sun irradiation' (specified by standard as 1360W/m^2 of solar energy) so in theory your panels could generate as much as 0.8A of current under standard illumination.

To design your vehicle, you will need to know the electrical current and voltage that your panel generates. The current generated by a solar module can be approximated by

$$I = I_0 - I_1(e^{qV/nkT} - 1) \tag{1}$$

Here:

1. I_0 is the current generated by the photovoltaic effect. The value of I_0 depends on how the panel is illuminated – for full sunlight, it should be 200mA for each module (800mA total). In your application, the value of I_0 may be more or less than this, and will vary with the distance of the modules from the incandescent light bulbs that illuminate the cells.
2. I_1 is the `reverse saturation current' (the small electric current that flows through the cell when it is not illuminated, and an external power source such as a battery applies a negative voltage across its terminals). The value of $I_1 \approx 30\mu A$ (micro-amps, i.e. 30x10^{-6}A)
3. n is a dimensionless constant that depends on the number and characteristics of the photovoltaic cells in the module;
4. q is the magnitude of the charge of an electron 1.609×10^{-19} C
5. V is the voltage across the cell (this will depend on what is connected to the cell)
6. k is the Boltzmann constant 1.380×10^{-23} J/K
7. T is temperature, in Kelvin.



A typical series current-voltage curves for a module is sketched in the figure.

To use this formula, you will need to determine values for the constants I_0, n in the formula, but for preliminary calculations you can assume $I_0 = 0.2A$, $n=16$.

Some experimental measurements of the current and voltage characteristics for the panels are listed in the tables below. These data are for *one* panel – you will be using four panels in parallel (by connecting the wires from each panel directly to the motor terminals) so the current supplied to the motor will be four times the current generated by one panel. The temperature of the panels in all the measurements was 80F.

Panel 6" from light source	
Voltage (V)	Current (mA)
0.512	258
1.064	259.5
1.607	259
2.171	258
2.698	255.5
3.124	253
3.261	224
3.392	167.5
3.46	142
3.503	123
3.512	111.5
3.537	99
3.56	89.5

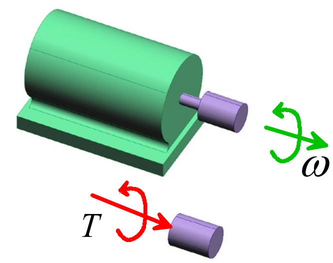
Panel 10" from light source	
Voltage (V)	Current (mA)
0.326	170
0.664	170
1.004	169.5
1.317	167
1.659	168
2.012	169.5
2.315	167
2.983	167.5
3.3	149
3.36	128.5
3.37	113.5
3.42	101
3.45	90.5

Note that these data are temperature sensitive – if the panels get too hot, they generate much less current than these measurements might suggest. So it's good to be conservative in your design calculations.

If you wish, you can use the electronic loads provided with test equipment to measure the current (out of your 4 panels) at several different values of voltage. These are quite tricky experiments to do, because the data tend to drift as the panels heat up, so if you have trouble you can use the tabulated data provided instead.

You can plot either the data provided or your own experimental data, and then find the values of I_0, n that make the theoretical curve fit (approximately) the data. You don't need to be too precise about this, because your design calculations are approximate and small errors in the values of I_0, n are negligible compared with the effects of other approximations.

A2 Characteristics of DC motors.



- An electric motor applies a *moment*, or *torque* T_m to an object that is coupled to its output shaft. The moment is developed by electromagnetic forces acting between permanent magnets in the housing and the electric current flowing through the winding of the motor.

- Power to drive the motor is supplied by connecting the motor to an electrical power source (the panels in your design, but in testing a power-supply is normally used). The power source applies a voltage V and current I to the motor.

The electric current I flowing through the winding is related to the voltage V and angular speed of the motor ω (in radians per second) by

$$I = (V - \beta\omega)/R \tag{2}$$

where R is the electrical resistance of the winding, and β is a constant that depends on the arrangement and type of magnets used in the motor, as well as the geometry of the wire coil.

The magnitude of the torque T_m exerted by output shaft of the motor is related to the electric current and the speed of the motor by

$$T_m = \begin{cases} \beta I - T_0 - \tau_0\omega & I > T_0/\beta \\ 0 & I < T_0/\beta \end{cases} \tag{3}$$

where T_0 and τ_0 are constants that account for losses such as friction in the bearings, eddy currents, and air resistance.

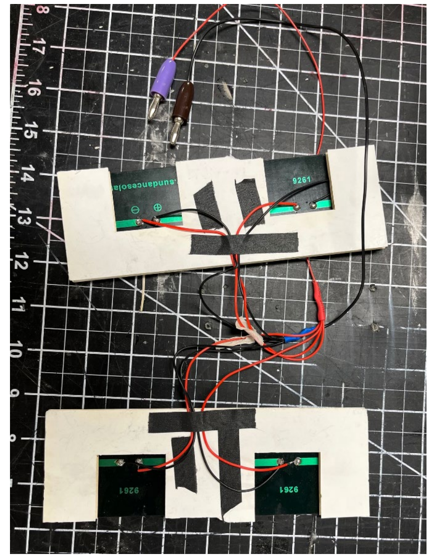
APPENDIX B: List of materials and tools

PARTS PROVIDED IN EACH KIT		
Part	Source	Mass
4x 200mA Solar Panels, mounted on a foam-core base (SEE INSTRUCTIONS ON NEXT PAGE!)	No longer commercially available ☹	90 grams (for all 4 panels).
Tamiya 12 speed gear motor (some motors are re-used from last year and so are already assembled) **SEE NOTE ON NEXT PAGE**	https://www.pololu.com/product/1683/	23 grams (assembled)
Predrilled wood base for Tamiya motor	Custom made by the TAs… You can screw the two plastic tabs provided with the motor to the base with the wood screws that come with the kit. The holes in the wood should line up with the perforated Al (or you can attach it to foam-core, etc)	7 grams
917D Multi-Ratio Gearbox Motor (backup only)	https://www.alliedelec.com/product/rs-pro/2389642/71133867/	55.6 grams (with all 6 gears – each gear has mass 1.4grams)
Push-in plugs for motor/panel connection	Connect the motor wires to the plugs to make it easier to quickly attach/remove your panels….	15 grams
Pololu 60 mm wheels (2)	https://www.pololu.com/product/1420	10 grams per wheel
Pololu 70 mm wheels (2)	https://www.pololu.com/product/1425	12 grams per wheel
Pololu 80 mm wheels (2)	https://www.pololu.com/product/1430	20 grams per wheel
Pololu 90 mm wheels (2)	https://www.pololu.com/product/1435	22 grams per wheel
Tamiya wheels: 36mm diameter (2) 55mm diameter (2)	https://www.pololu.com/product/1686	7 grams (large wheel) 5 grams (small wheel)
Tamiya 3mm shaft set	https://www.pololu.com/product/78	Typical shaft is 5-7 grams
Pololu mounting hub (2 pairs)	https://www.pololu.com/product/1078	3 grams (for 1 hub)
3/16" collars (4)	These help hold axles in place	3 grams each

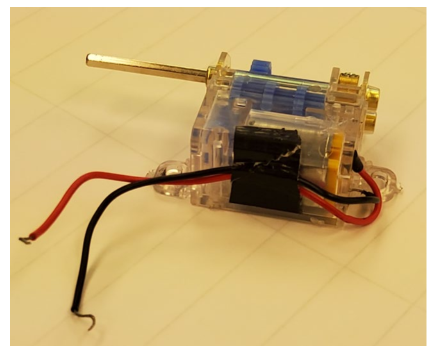
MATERIAL AVAILABLE IN BDW		
16 gage perforated aluminum	McMaster 9232T181	2031 grams/m^2
Foam-core board		473 grams/m^2
Masking tape		-
4-40 nut/machine screw assortment		-

Solar Panels: Kits are provided with solar panels mounted on a single sheet of foam-core and wired together in parallel. You will need to separate the four panels into two pairs to mount on each side of your vehicle (see the picture) – you can cut the foam-core with box cutters (be careful not to damage the panels or wiring when you do this). Be sure to tape the wires down to the foam core afterwards so you don't accidentally pull the wires off the solder tabs.

We also have a limited supply of un-mounted panels if you would prefer to mount your own. You will need to solder wires to the tabs on the panels and design your own mounting system.



Motor Wires: the wires pull off the motor tabs very easily. After assembling your motor, tape the wires to the motor housing as shown in the picture.



3D printing parts for solar cars (optional - just for fun). You don't need to 3D print anything, and if you do print parts it won't affect your project grades in any way. But if your group is interested in 3D printing parts for your solar car, please

- **Sign up your team-members into a project group on Canvas by Wed April 27**
- **Optional:** Arrange for one of your group members to pick up the kit of parts for your car from **room 157 Barus-Holley between 9am and 12:00 noon on Wed April 27** (this is optional, but it will help you with your CAD if you know what the parts look like). You will need to tell us your group number when you sign out your kit so we can keep track of them.
- Design your parts using your favorite CAD program, and export a .STL file
- Estimate print time on your own by putting in your .stl into Prusaslicer and generating a .gcode (instructions for the printer). Use 0.2mm speed and 15% infill. Larger parts = larger print time. **The maximum print time is 4 hours.** We will do our best to be flexible, but longer prints could mean longer delays in getting parts to you.
- Upload .STL files for your parts to Canvas as early as possible, and no later than noon on Monday May 2. In the comments section please let us know the print time, and please let us know if you think you will need supports or a brim for your print.
- We will print your parts and try to get them to you by Wednesday.
- We would prefer for you to upload your parts for us to print instead of printing them on your own (if you are trained in 3D printing) to avoid large queues for the printers. We have a couple of printers dedicated to ENGN40 next week, but many other students have final projects to print.
- For questions about printing please contact Sri Bellala venkatsai_bellala@brown.edu

ミニモーターギヤボックスの ギヤ比一覧

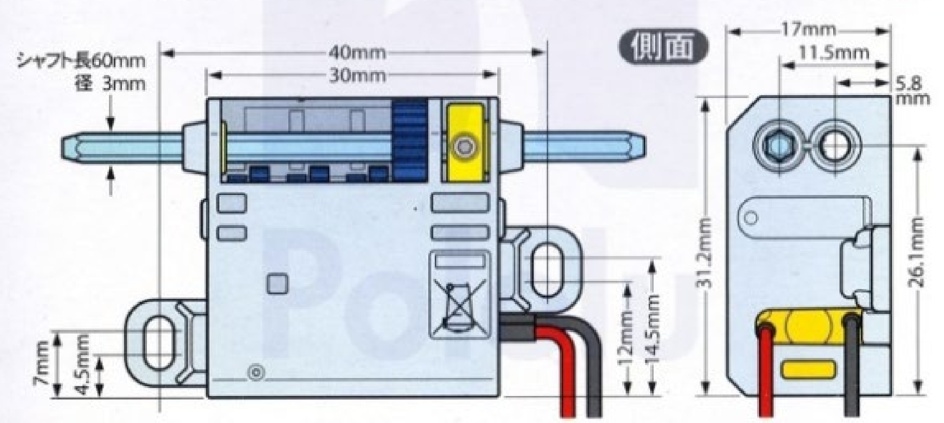
※このモーターの基本電圧は3Vです。
回転数・トルクは電源3V時の参考値です。

ミニモーター標準ギヤボックス — MINI MOTOR GEARBOX
ミニモーター低速ギヤボックス — MINI MOTOR LOW-SPEED GEARBOX
ミニモーター多段ギヤボックス — MINI MOTOR MULTI-RATIO GEARBOX

高速

ギヤ比 GEAR RATIO	4.6	5.1	7.5	9.5	9.7	10.8
回転数 (rpm)	1,360	1,224	842	663	647	583
トルク (gf·cm)	23	25	37	47	48	53
ギヤ比 GEAR RATIO	15.7	19.9	20.4	22.6	32.9	41.8
回転数 (rpm)	401	316	308	277	191	150
トルク (gf·cm)	78	98	99	110	159	202
ギヤ比 GEAR RATIO	42.8	47.5	71.4	79	87.8	89.9
回転数 (rpm)	147	132	88	80	72	70
トルク (gf·cm)	202	225	236	369	410	420
ギヤ比 GEAR RATIO	99.8	149.9	188.7	209.7	314.9	661.2
回転数 (rpm)	63	42	33	30	20	9
トルク (gf·cm)	467	470	851	946	866	1,455

低速



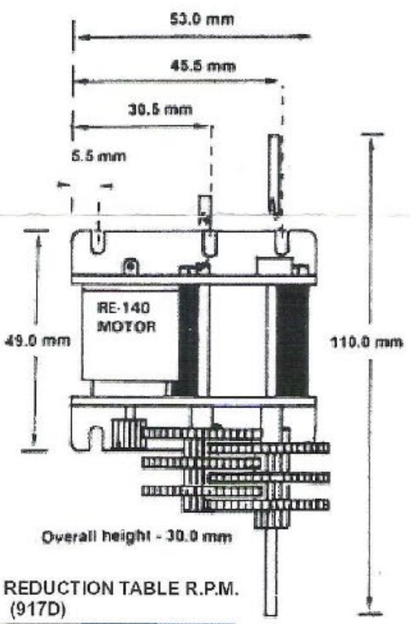
Typical operating voltage:	3 V
Gear ratio options:	4.6, 5.1, 9.7, 10.8, 20.4, 22.6, 42.8, 47.5, 89.9, 99.8, 188.7, 209.7 :1
No-load motor shaft speed @ 3V:	8400 rpm[1]
No-load current @ 3V:	60 mA[2]
Stall current @ 3V:	600 mA
Color:	clear

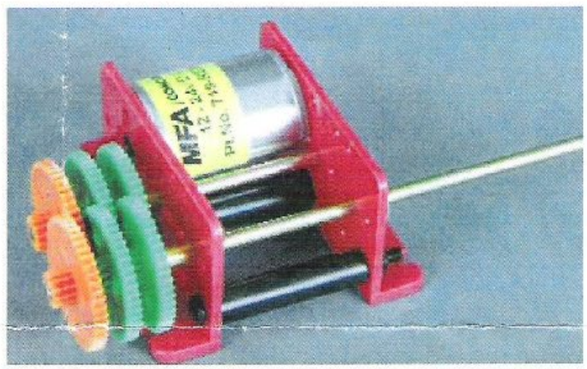
Notes:
The three rows in the table are gear ratio (only those highlighted in green are available), output speed (rpm) and ouput torque (at very low speed, in gram-cm). Be careful with unit conversion to Nm.
1 A theoretical speed of the gearbox output shaft can be computed by dividing this speed by the gear ratio.
2 This is the no-load current of the motor when disconnected from the gears in the gearbox; the no-load current of the entire gearbox with the motor connected will be slightly higher and will vary depending on the gear ratio.

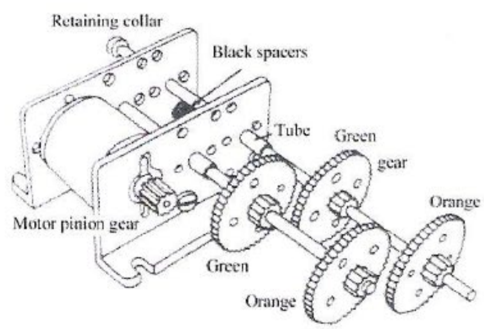
Images SI Inc.
109 Woods of Arden Road
Staten Island NY 10312
718.966.3694 Tel
718.966.3695 Fax
www.imagesco.com

917D Multi-Ratio Gearbox Datasheet

GEARBOX DIMENSIONS.
(917D)







REDUCTION TABLE R.P.M.
(917D)

	1.5V	3.0V
4:1	1850	3700
16:1	462	926
64:1	115	231
256:1	29	57
1024:1	7	14
4096:1	2	4

The unit operates on 1.5 & 3V DC power sources, either battery or suitable transformer. Its simple versatile design and sturdy construction make it suitable for a host of uses from powering models and robots to teaching the principles of mechanics. Current consumption depends on eventual load but is within the range of .2 to .8 amps. The output shaft is 3mm diameter.

MODEL	VOLTAGE		NO LOAD		AT MAXIMUM EFFICIENCY						STALL TORQUE	
	OPERATING RANGE	NOMINAL	SPEED	CURRENT	SPEED	CURRENT	TORQUE		OUTPUT	EFF		
			R.P.M.	A	R.P.M.	A	oz - in	g - cm	W	%	oz - in	g - cm
RE - 140	1.5 - 3.0	3.0v CONSTANT	14800	0.300	11500	1.05	0.152	10.92	1.29	41.03	0.68	49.0

Backup motor – these will be provided if we run out of Tamiya motors (there are supply issues….)