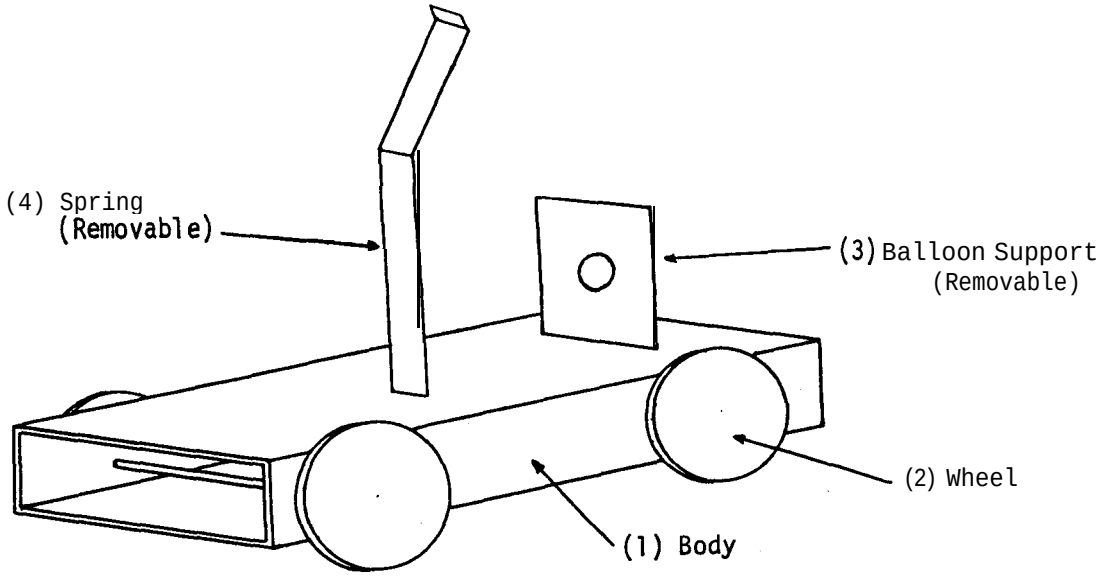
III. CARTS

A. FORCE AND MOTION CARTS

The carts described in this section are presented in increasing order of sophistication, ranging from the simplest cart which can only be used for qualitative observation to the more sophisticated carts which can be used for quantitative experimentation of the relationship between force, mass and acceleration.

A. FORCE AND MOTION CARTS

Al. Elementary Cart *



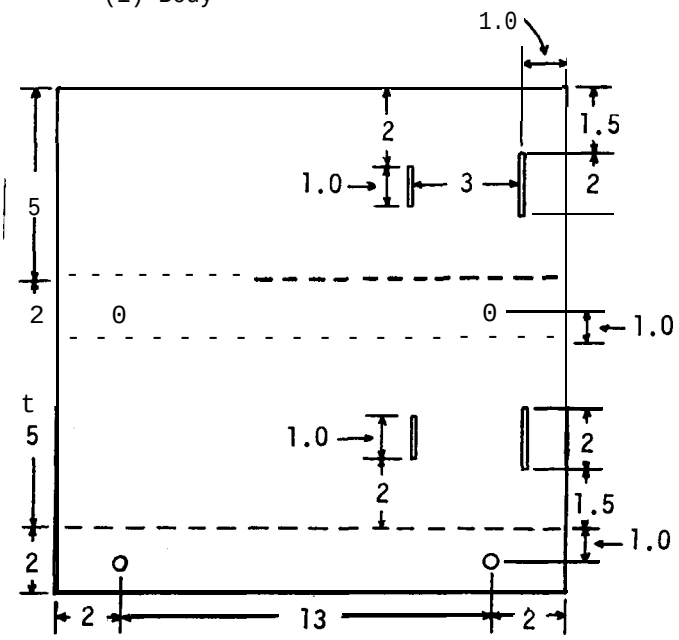
a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Body	1	Cardboard Sheet (A)	15 cm x 14 cm
(2) Wheels	2	Wooden Spools (B)	Diameter of spool ends approximately 4 cm
	2	Coat Hanger Wire (C)	8 cm long, 0.2 cm diameter
	1	Drinking Straw (D)	--
(3) Balloon Support	1	Cardboard Sheet (E)	4 cm x 7 cm
	1	Balloon (F)	--
(4) Spring	1	Packing Case Band (G)	11 cm long, approximately 1.2 cm wide
	1	Washer (H)	Approximately 17 g

*Adapted from Nick Oddo and Edward Carini, Exploring Motion, An Exploring Science Book, (USA: Holt, Rinehart and Winston Inc., 1964), pp 24-27.

b. Construction

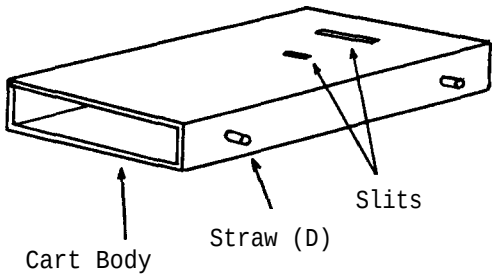
(1) Body



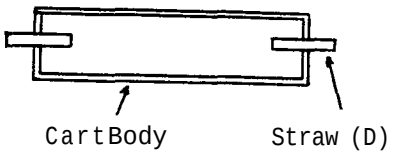
Cardboard (A)

Draw dotted lines on the piece of sturdy cardboard (A) and make four slits and four axle holes as illustrated in the diagram. Fold the cardboard along the dotted lines to make a box, fastening the free sides together with the help of adhesive tape.

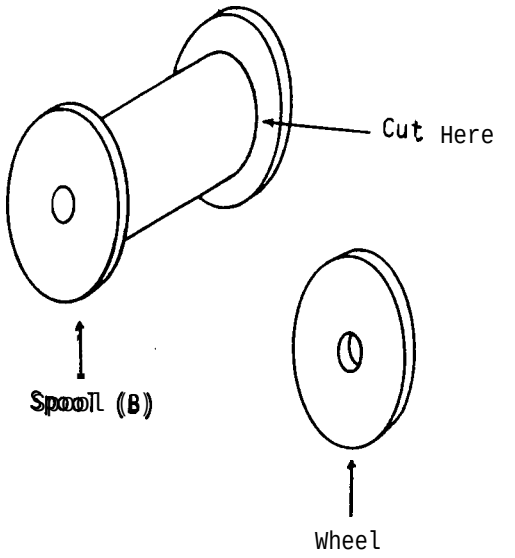
(2) Wheels



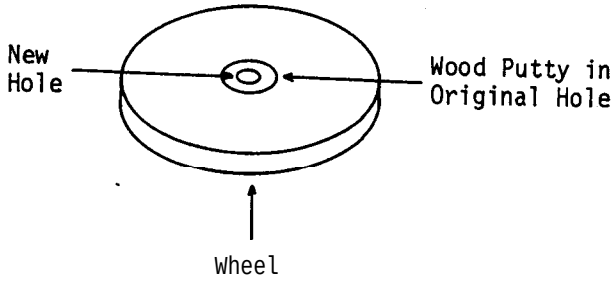
Cut four equal sections (each 1 cm long) from a standard drinking straw (D). Place each section into an axle hole in the body of the cart, and glue firmly in position. The straw sections act as bearings for the axles as well as spacers between the wheels and the body of the cart.



Cross Section



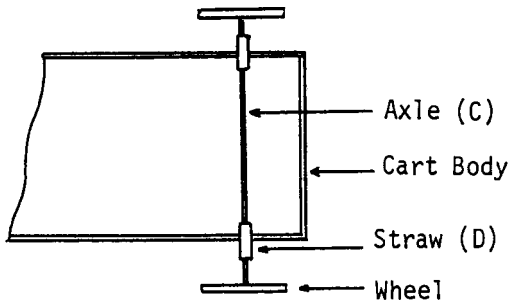
Cut the four wheels from the ends of the two wooden spools (B). Fill the spool holes (0.5 cm diameter) with wood putty and allow the putty to dry hard.



Cut two lengths of wire (C) **from wire coat hangers to serve as axles for the cart.**

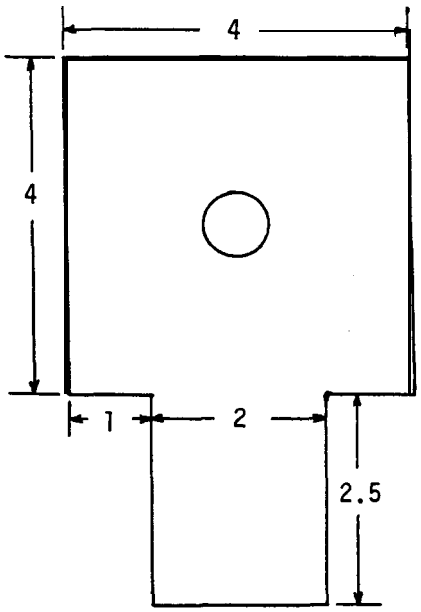
Drill holes, slightly less than 0.2 cm in diameter, through the exact center of each wheel, and put a little epoxy resin in the holes.

Tap the end of one axle into one of these holes, checking carefully to insure that the axle is at right angles (90") to the wheel, thus avoiding subsequent wheel wobble.



Insert the axle through the body of the cart, and attach a second wheel by the same process. Repeat the procedure with the remaining two wheels and axle, thus providing the cart with front and rear wheels.

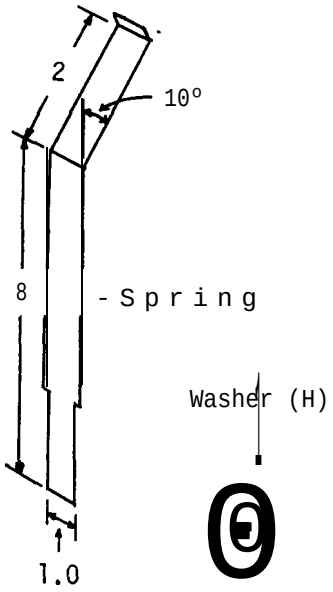
(3) Balloon Support



Cardboard (E)

Cut the strong cardboard (E) to a "T" shape as shown. Make a hole (diameter 1 cm) in the center of the top portion. Insert the support through the pair of slits closest to the end of the cart body. Use a rubber balloon (F) to provide acceleration for the cart [see Note (i)].

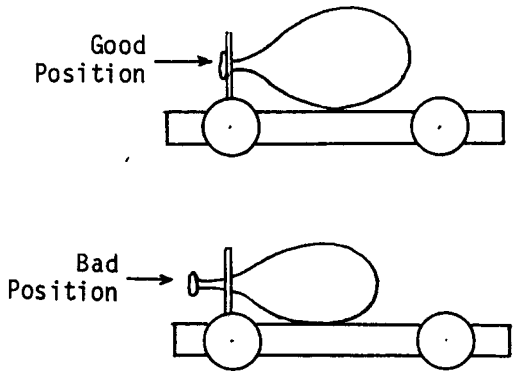
(4) Spring



Cut the packing case band (G) as indicated to make the spring. To facilitate the throwing of the washers (H) by the spring, bend the top end of the packing case band at an angle. Insert the spring through the remaining slits in the cart.

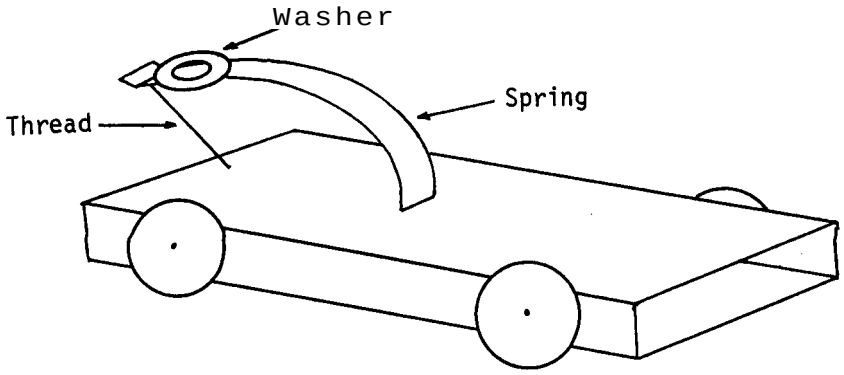
c. Notes

(i) Spherical balloons, as opposed to sausage-shaped ones, may be held in the balloon support (so long as the spring is removed), and are capable of accelerating the cart by the expulsion of air. The cart will be accelerated most efficiently if the open end of the balloon is held in such a way as to prevent it flopping from side to side with resultant dissipation of energy in all directions.



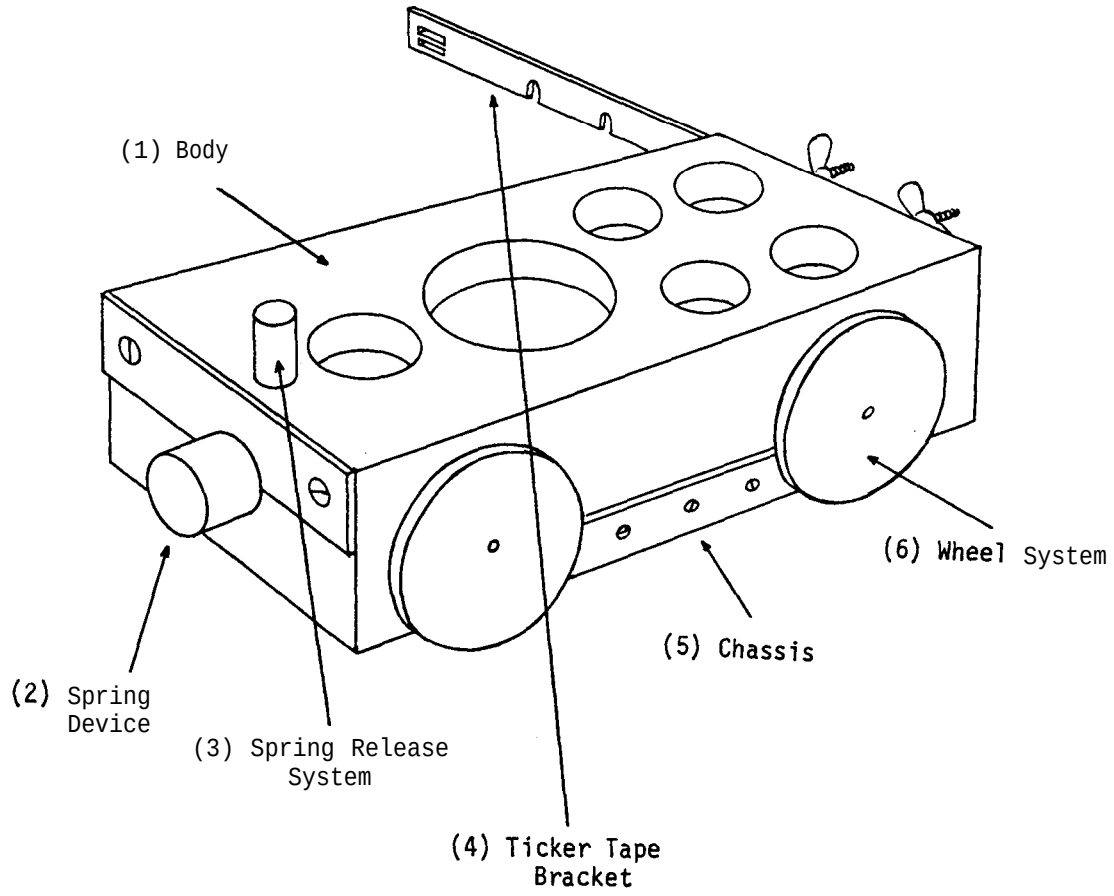
Not only does the cart motion illustrate action and reaction, but it also demonstrates accelerated motion due to a force. Once the balloon is deflated the acceleration ceases and the cart decelerates to a stop.

(ii) Take a length of strong thread (say 15 cm long), and tie the top end of the spring to the end of the cart in such a way that the top end of the spring is almost horizontal. Place a washer on the top end of the spring. If a burning



match is applied to the thread, the spring will be released and eject the washer forward, while the cart will be propelled backwards, thus offering another demonstration of action and reaction.

A2. Lightweight Cart ©



a. Materials Required

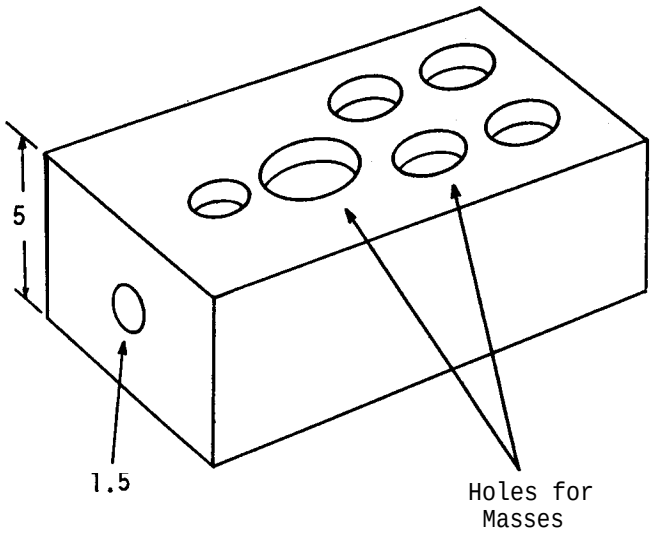
Components	Qu	Items Required	Dimensions
(1) Body	1	Wood (A)	15 cm x 6 cm x 5 cm
(2) Spring Device	1	Steel Wire (B)	80 cm long, 0.09 cm diameter
	1	Wood Dowel (C)	10 cm long, 1.2 cm diameter
	1	Rubber Stopper (D)	Approximately 2.5 cm diameter, and 1.5 cm long
	1	Screw (E)	1 cm long
(3) Spring Release System	1	Metal Plate (F)	6 cm x 1.5 cm x 0.05 cm

© From Reginald F. Melton, Elementary, Economic Experiments in Physics, Apparatus Guide, (London: Center for Educational Development Overseas, 1972), pp 39-46.

	2	Screws (G)	1.5 cm long
	1	Wood Dowel (H)	3.5 cm long, 0.8 cm diameter
	1	Steel Wire (I)	#30, 3.5 cm long
(4) Ticker Tape Bracket	1	Aluminum Sheet (J)	15 cm x 1.2 cm x 0.05 cm
	2	Bolts (K)	0.2 cm diameter, 2 cm long
	2	Wing Nuts (L)	0.2 cm internal diameter
(5) Chassis	2	Packing Case Steel Bands (M)	Approximately 15 cm x 1.5 cm x 0.02 cm
(6) Wheel System	2	Wooden Spools (N)	Approximately 4 cm diameter
	2	Coat Hanger Wire (0)	10 cm long, 0.2 cm diameter
	1	Masking Tape (P)	1 cm wide
	--	Washers (Q)	--

b. Construction

(1) Body

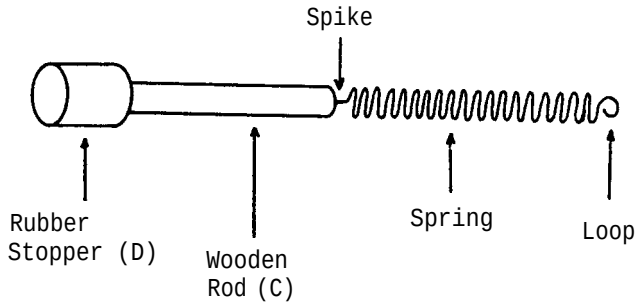


Bore a hole from the center of one end of wood (A) to the center of the other end, in order to accommodate a spring device. The diameter of the hole (1.5 cm) should be slightly larger than that of the spring (1.2 cm).

Bore holes into the top surface of the wood (A) to accomodate six masses (see I/C2), namely one 100 g mass (diameter 2.5 cm), four 200 g masses (diameter 2.5 cm) and one 500 g mass (diameter 4.0 cm). The holes should not be so deep as to cut into the horizontal hole for the spring.

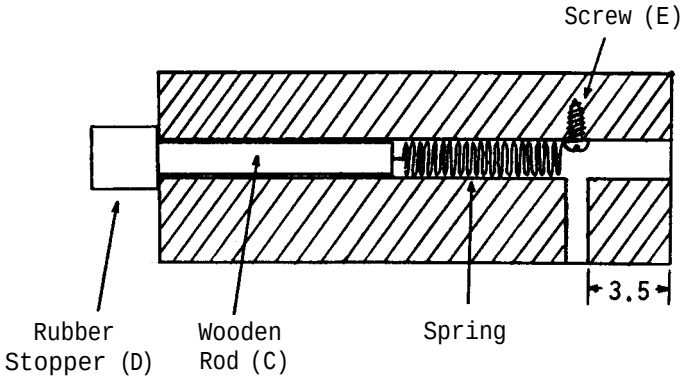
(2) Spring Device

Wind about 60 cm of the steel wire (B) into an open spring approximately 8.5 cm long,



1.2 cm in diameter, and with about 0.5 cm separation between each turn. (A method of winding the spring is described under I/C4). Straighten out one end of the spring into a spike and the other to a horizontal loop.

Attach the spring of one end of the wooden rod (C) by means of the spike and epoxy resin. Attach the rubber stopper (D) to the other end of the rod.

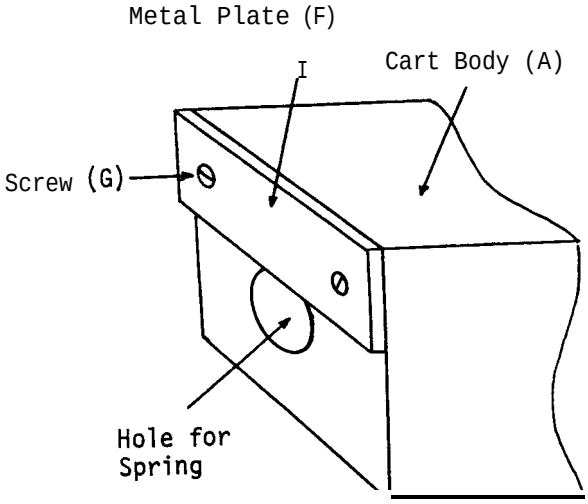


Cross Section
(Side view)

Bore a hole into the bottom of the cart body so that it meets the bore hole for the spring 3.5 cm from the end of the body. Then insert the screw (E) to anchor the loop end of the spring.

Ideally, two or three alternative springs of varying thickness and length should be made for trial purposes. The ultimate spring selected will be such that if two identical carts (one carrying three times its own weight) are placed end to end, and the spring device on one cart is then released, both carts will move apart a sufficient distance at uniform velocity to enable a measure of their initial separation velocities to be recorded.

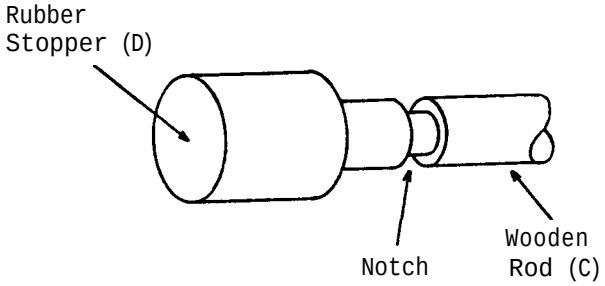
(3) Spring Release System

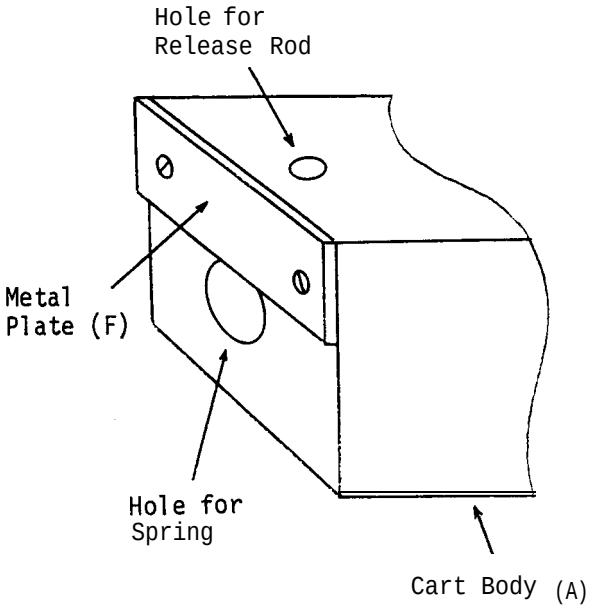


Fasten the metal plate (F) (brass, steel, etc.) onto the front of the cart with two screws (G) so as to just overlap the top of the hole for the spring.

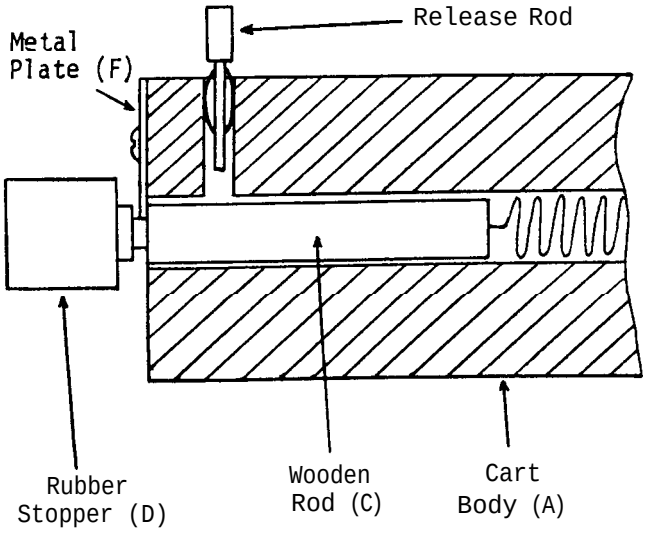
File a small notch around the wooden rod (C) on the spring device, close to the stopper.

It is thus possible to compress the spring into the hole, and hold it in position by means of the notch and metal plate.



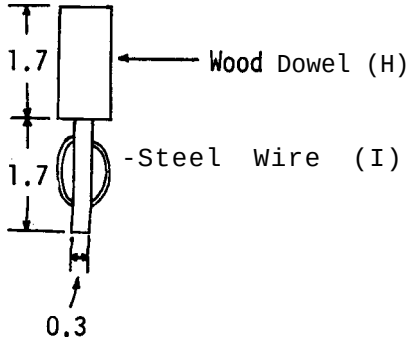


Bore a vertical hole (diameter 0.5 cm) into the top of the cart, near the front end, so that it meets the horizontal bore hole for the spring. The small wooden rod (H) (release rod) inserted into this hole, and pressed against the horizontal rod of the spring device itself, will release the spring from its state of compression. (The need to have the diameter of the spring bore hole slightly



Cross Section

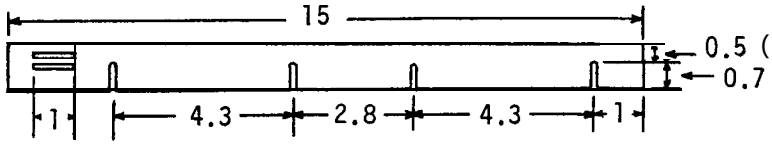
greater than that of the spring and attached rod should now be clear, for it is an essential requirement if the spring is to be released).



Release Rod

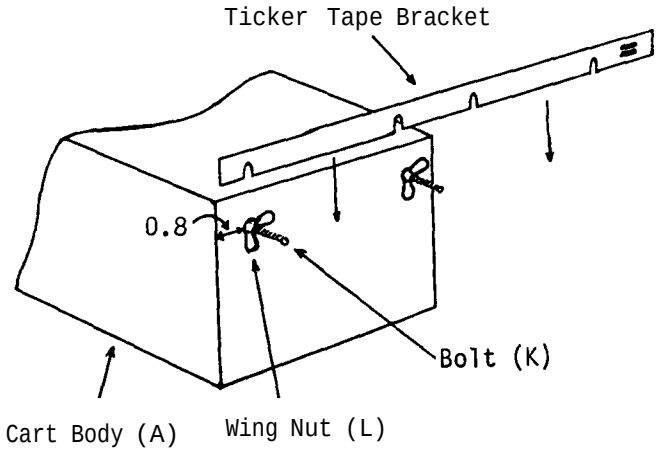
Cut the wood dowel (H) to the dimensions illustrated. The rod should be capable of moving freely in its bore hole, but at the same time it should not be so loose that it is easily lost. To prevent losing it, thread a thin piece of steel wire (I) through the rod so that it acts as a spring contact between the sides of the rod and the bore hole.

(4) Ticker Tape Bracket

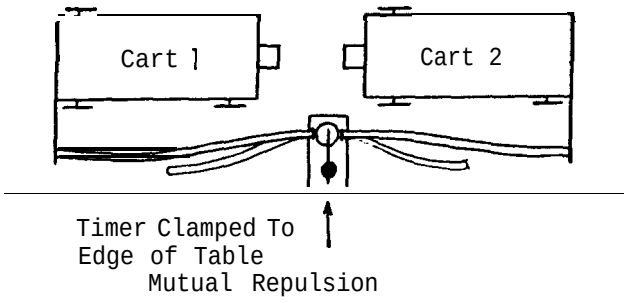


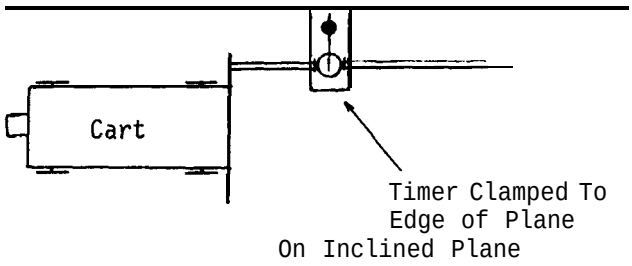
Sheet Metal (J)

Cut the ticker tape bracket from the sheet of metal (J) (brass, aluminum) which should be reasonably rigid, Make slits (0.1 cm wide) near the end to take the ticker tape, and slots (0.35 cm wide) along the bottom to enable the bracket to be attached to the bolts (K) at the



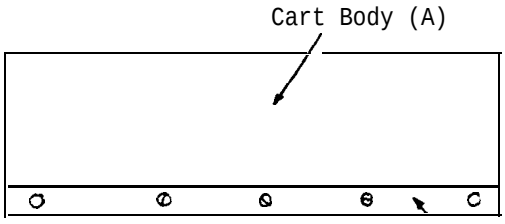
rear of the cart. Wing nuts (L) should be used to fasten the bracket in position.





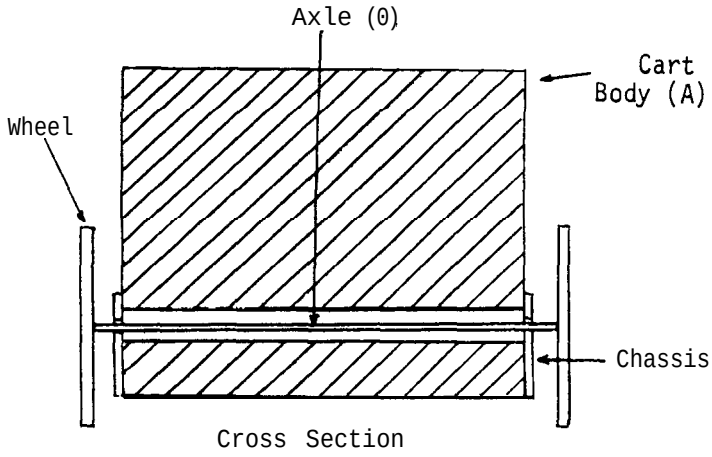
The purpose of the bracket is to insure that ticker tape attached to the cart is in line with the guides of the timer during any experiment, thus reducing friction. Two typical examples are illustrated when carts are mutually repulsed from one another, and when a single cart runs down an inclined plane.

(5) Chassis



Side View

Drill two horizontal holes (0.5 cm in diameter) through the cart body to permit passage of the front and rear axles. Make these holes 1.0 cm from each edge of the cart body (A). Cut the chassis from metal packing case bands (M). Drill five holes along the length of the

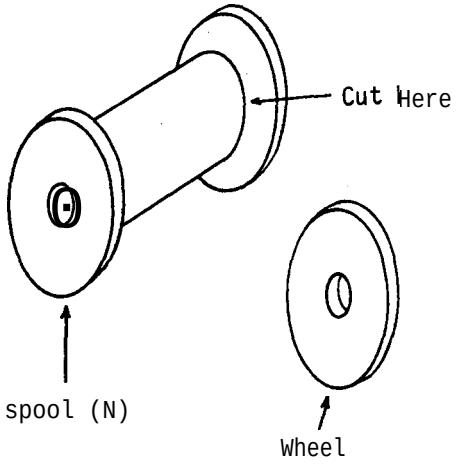


Cross Section

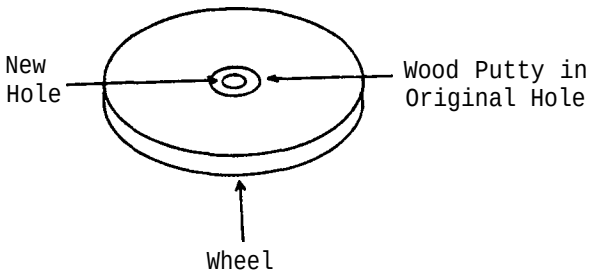
strip, two (diameter 0.3 cm) to coincide with the centers of the axle holes and three to enable the strip to be attached firmly to the body with screws.

The axles of the cart will in fact pivot in the chassis holes and not on the wooden holes through the cart, thus reducing friction.

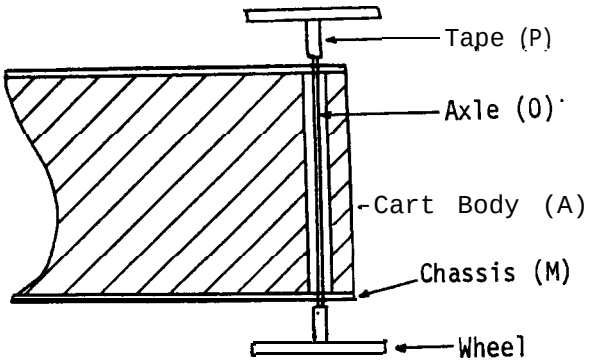
(6) Wheel System



Cut the four wheels from the ends of two wooden spools (N). Fill the spool holes with wood putty and allow the putty to dry hard.



Cut two lengths of wire (0) from wire coat hangers to serve as axles for the cart. Drill holes, slightly less than 0.2 cm in diameter, through the exact center of each wheel, and put a little epoxy resin in the holes.



Cross Section

Tap the end of one axle (0) into one of these holes, checking carefully to insure that the axle is at right angles to the wheel (thus avoiding subsequent wheel wobble).

Insert the axle through the body of the cart, and attach a second wheel by the same process. Repeat the procedure with the remaining two wheels and axle, thus providing the cart with front and rear wheels.

Make small spacers for all four wheels from masking tape (P), in each case wrapping it around the axle (next to the wheel) until it produces a cylindrical spacer 1 cm long and 0.5 cm in diameter.

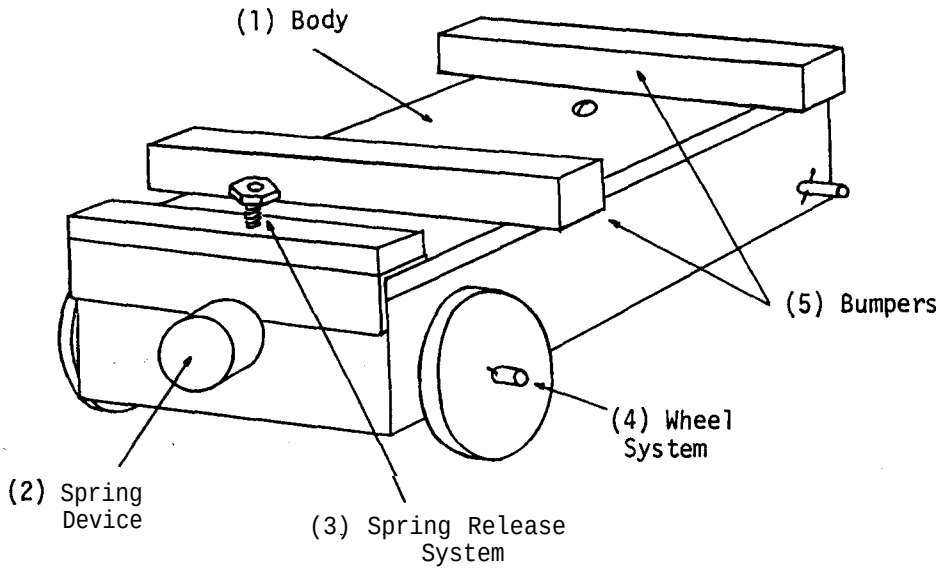
A little soap applied to each axle will serve as a lubricant between the axle and chassis contact points.

It is convenient to adjust the mass of the completed cart to the nearest 100 g. This may be done by shaving wood off the top or bottom surface of the body of the cart, or by adding washers to the body of the cart. In this case holes were drilled in the bottom of the cart, and washers (Q) fixed in the holes with screws. In this way the mass of the cart was adjusted to 400 g.

c. Notes

(i) This cart will inevitably be affected by friction more than a cart made with ball bearing wheels (III/A3). However, a full range of force and motion experiments may be performed with the cart if an inclined plane is used to compensate for friction affecting the cart. Simply adjust the inclination of the plane prior to any experiment so that the cart runs down the plane with constant velocity, the slope of the plane just compensating for the effect of friction.

A3. Heavyweight Cart

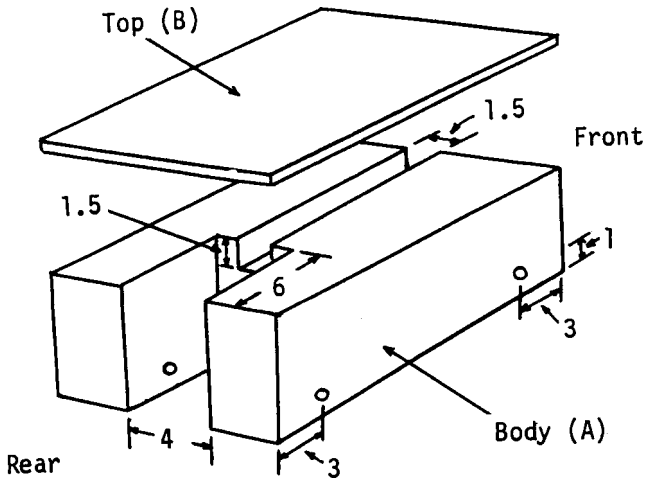


a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Body	1	Wood (A)	30 cm x 8 cm x 4 cm
	1	Plywood (B)	30 cm x 8 cm x 0.5 cm
(2) Spring Device	1	Wooden Dowel (C)	16 cm long, 1.2 cm diameter
	1	Roll of Steel Wire (D)	0.09 cm diameter
	1	Rubber Stopper (E)	Approximately 2.5 cm diameter
	1	Screw (F)	4 cm long, 0.2 cm diameter
(3) Spring Release System	1	Aluminum Sheet (G)	8 cm x 3 cm x 0.05 cm
	1	Bolt (H)	3 cm long, 0.3 cm diameter
	2	Nuts (I)	0.3 cm internal diameter
	1	Wooden Strip (J)	8 cm x 2 cm x 0.5 cm
(4) Wheel System	3	Ball Bearing Wheels (K)	Approximately 5 cm diameter
	1	Wooden Dowel (L)	22 cm long, 0.5 cm diameter
	4	Nails (M)	Approximately 2 cm long
(5) Bumpers	2	Wood (N)	12 cm x 2 cm x 2 cm

b. Construction

(1) Body

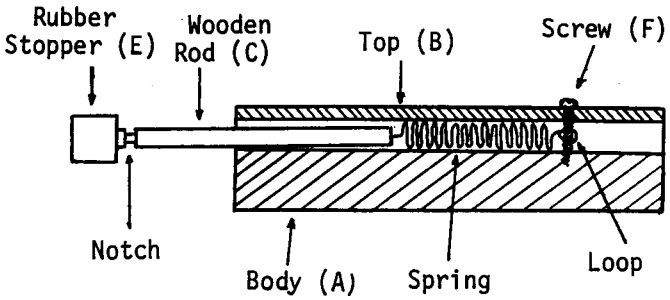


Cut the body of the cart from the piece of wood (A). Drill horizontal holes (diameter D.5 cm) close to the front and rear of the cart to hold the axles of the wheel system.

Using a saw and chisel, cut a horizontal slot in the top surface of the cart to contain the spring device, and a vertical slot in the rear of the cart to accommodate the rear wheel.

Use the piece of plywood (B) to make a top plate for the cart, and nail it onto the main body.

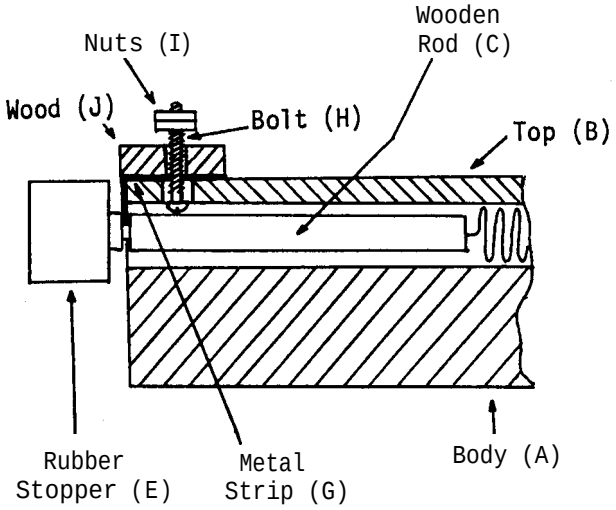
(2) Spring Device



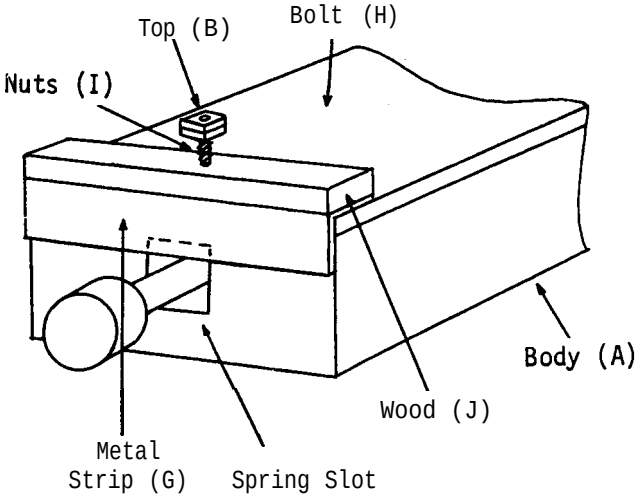
Cross Section

Make the spring device according to the instructions given for the previous cart (III/A2), but according to the dimensions indicated here. The spring, made from the steel wire (D), should be 1.2 cm in diameter and 16 cm long (excluding the spike and loop made on the end of the spring). Nail the rubber stopper (E) onto the end of the wooden rod (C), and make a notch (0.2 cm deep) around the rod about 0.5 cm from the end. Place the spring device in the appropriate slot in the cart, and anchor it in position by means of the screw (F) inserted through the top plate of the cart in such a way as to pass through the loop on the end of the spring.

(3) Spring Release System



Cross Section



(4) Wheel System

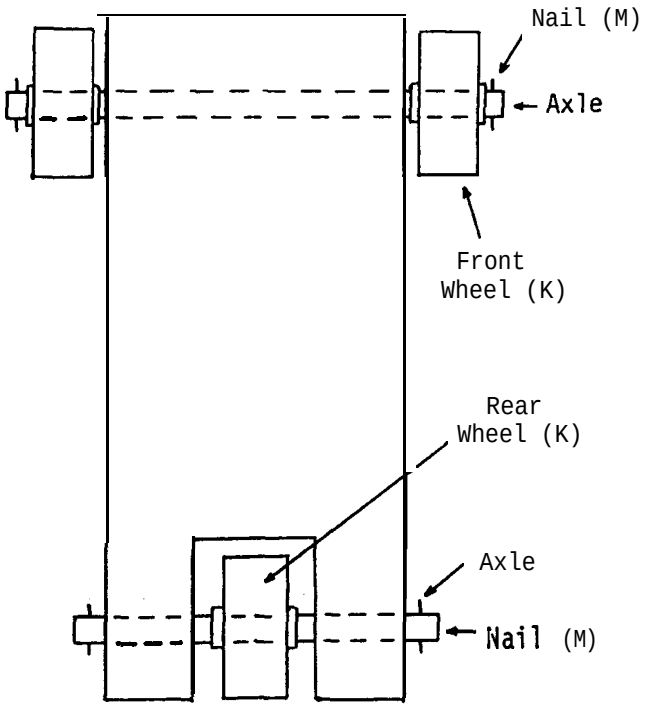
Bend the sheet of aluminum (G) into an "L" shape (8 cm wide, 2 cm tall, with a base of 1 cm). Attach the sheet to the front of the cart so that the base of the sheet just overlaps the slot for the spring device. In this way the spring may be compressed and held in position by means of the metal sheet and the notch in the rod.

Use the bolt (H) and two appropriate nuts (I) to serve as a releasing device, and bore a hole through the metal sheet and top plate of the cart, 1 cm from the front, so as to expose the rod of the spring device.

The diameter of the hole should be large enough to admit the head of the selected bolt.

Drill a hole through the middle of the wood strip (J). The diameter of the hole should be just large enough to admit the bolt (H), but not the head of the bolt. Place the bolt through the strip with the bolt head beneath the strip, such that it sits in the newly drilled hole in the body of the cart. Nail the strip in position on the front of the cart, and add the two locking nuts (I) to the end of the bolt.

Three ball bearing wheels (K) will have to be purchased (possibly imported) for this

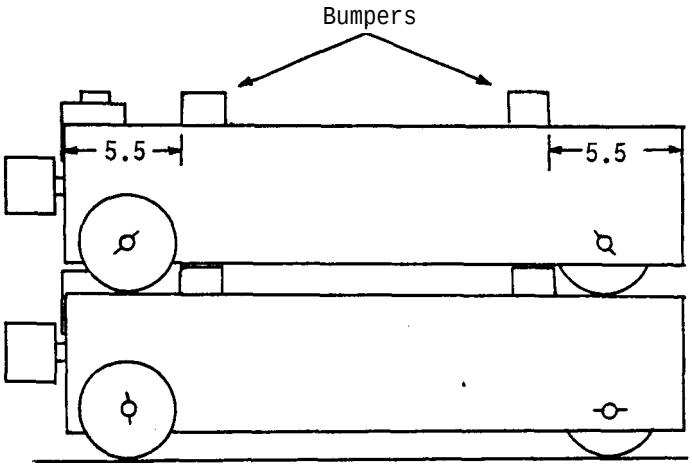


Top View

cart. Cut two axles from the wooden dowel (L). Make the front axle 13 cm, and rear 9 cm long (both 0.5 cm in diameter in this instance). The diameter of the dowel should be the same as the internal diameter of the ball bearing wheels, thus providing a tight fit.

Pass the axles through the axle holes in the cart and fit the wheels appropriately on the axles. Take the four small nails (M), and drill holes of the same diameter as the nails through the axle ends. Insert the nails through the holes, thus securing the axles and wheels in position.

(5) Bumpers



Side View

Use the two strips of wood (N) as bumpers. Nail them in position on top of the cart in such a way that they will hold a second cart (placed on top of the first) firmly in position.

c. Notes

(i) The final weight of the cart will be of the order of 1,000 g. With ball bearing wheels this will not produce too much friction, while it will result in the moving cart having high momentum, and the cart will be little affected by what friction does exist.

(ii) A whole range of experiments related to force and motion will be found in many laboratory books, for example The Physical Science Study Committee, Laboratory Guide, (USA: D. C. Heath and Company, 1965).