N O T E

Free-Body Diagrams Revisited — I

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[Editor's Note: *When Jim Court sent me this collection of free-body exercises last spring, he knew that the exercises and solutions would occupy a large number of pages in TPT and kindly offered to provide readers with whatever we could not publish, saying "the disk and postage are on me." Jim passed away in June, a few weeks before his retirement. We know that teachers at all levels of physics use these diagrams and certainly Jim's work should not be lost. Therefore, this month and next we will run the material as the author sent it. Readers with questions or comments should contact Paul Hewitt, One San Antonio Place – 2D, San Francisco, CA 94133-4032.***]**

In 1993 *TPT* published a set of free-body exercises that I cooked up,[1] and in 1998, Ed van den Berg and Cor van Huis contributed a note[2] with some on-the-mark comments about what to do and what not to do when teaching free-body diagrams.

I have had a lot of feedback from the original printing, and in response I've prettied up the diagrams, added some, subtracted some, arranged them into categories, and included a separate set of solutions.

In discussing free-body diagrams with my colleagues, I find differences of opinion (surprise!) about how things should be done. One question is whether to draw all arrows showing exactly where a given force is applied. For example, in exercise LM-3, surface forces f (friction) and n (normal reaction force) are obviously exerted on the rock where it touches the surface, but if you are talking only about linear motion, you may prefer to draw these two forces and the weight as concurrent forces through the center of gravity.

Another arguable point is whether the arrows should be drawn directly on the picture of the object or on a disembodied spot that is separate from the picture, as in my 1993 version. This time I've opted for simplicity (and for saving space) by drawing the arrows directly on the picture.

Whatever you do, be consistent! Feel free to photocopy whatever you want and use them for your classes as you see fit.

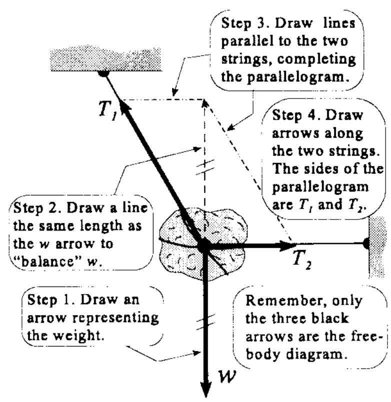
References

1. J. E. Court, "Free-body diagrams," *Phys. Teach.* **31**, 104-108 (February 1993).
2. E. van den Berg and C. van Huis, "Drawing forces," *Phys. Teach*. **36**, 222-223 (April 1998).

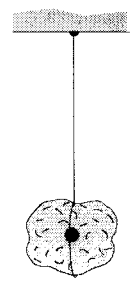
Free-Body Exercises: Linear Motion

In each case the rock is acted on by one or more forces. All drawings are in a vertical plane, and friction is negligible except where noted. Draw accurate free-body diagrams showing all forces acting on the rock. LM-1 is done as an example, using the "parallelogram" method. For convenience, you may draw all forces acting at the center of mass, even though friction and normal reaction force act at the point of contact with the surface. Please use a ruler, and do it in pencil so you can correct mistakes. Label forces using the following symbols: w = weight of rock, T = tension, n = normal reaction force, f = friction.

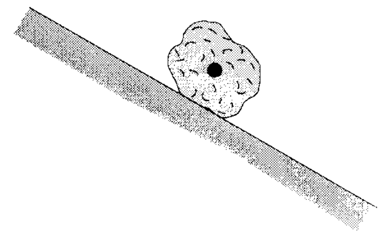
LM-1. Equilibrium (Example)



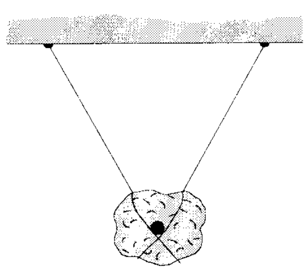
LM-2. Equilibrium



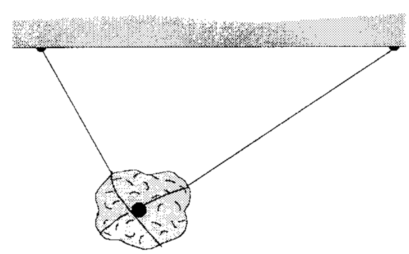
LM-3. Friction prevents sliding.



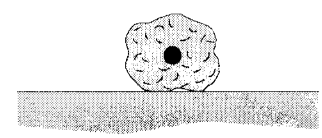
LM-4. Equilibrium



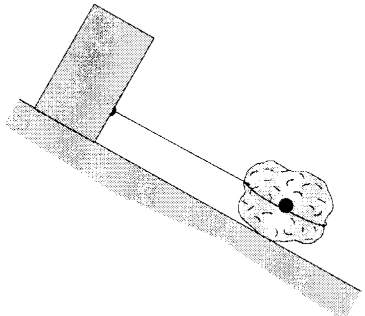
LM-5. Equilibrium



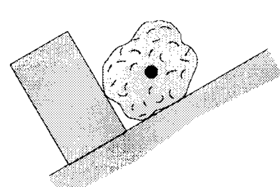
LM-6. Equilibrium



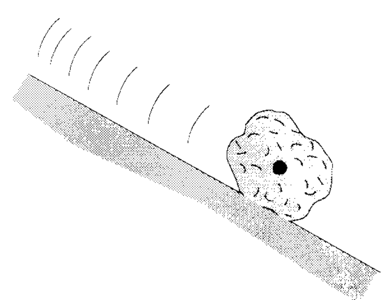
LM-7. Equilibrium



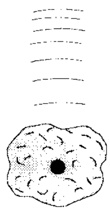
LM-8. Equilibrium



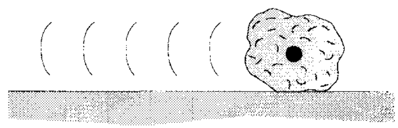
LM-9. Rock is sliding on a frictionless incline.



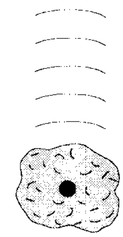
LM-10. Rock is falling. No friction.



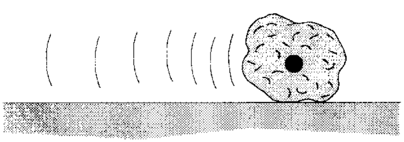
LM-11. Rock is sliding at constant speed on a frictionless surface.



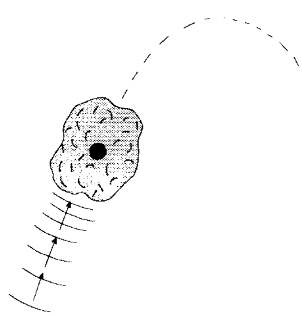
LM-12. Rock is falling at constant (terminal) velocity.



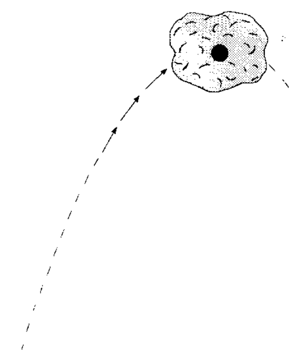
LM-13. Rock is decelerating because of kinetic friction.



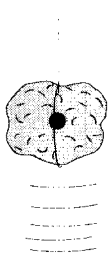
LM-14. Rock is rising in a parabolic trajectory.



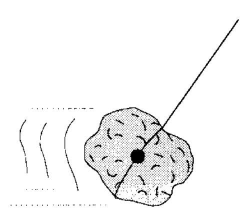
LM-15. Rock is at the top of a parabolic trajectory.



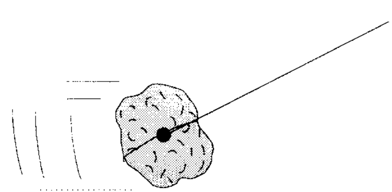
LM-16. Rock is tied to a rope and pulled straight upward, accelerating at 9.8 m/s^2. No friction.



LM-17. Rock is tied to a rope and pulled so that it moves horizontally at constant velocity. (There must be friction.)



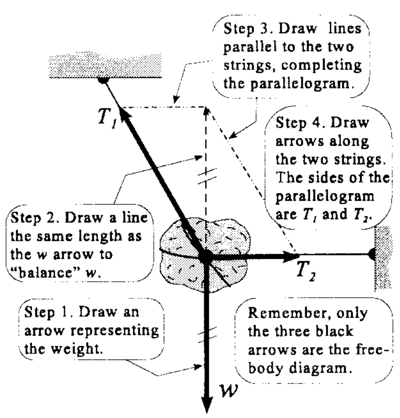
LM-18. Rock is tied to a rope and pulled so that it accelerates horizontally at $2g$. No friction.



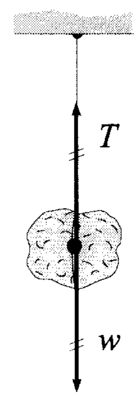
Free-Body Solutions: Linear Motion

The dashed arrows and construction lines in these solutions are for explanation only, and **not** part of the finished diagram. The free-body diagram in each case consists of only the dark, solid arrows. Forces of the same magnitude or lines of the same length are indicated by the same number of "tick" marks drawn through the two lines or arrows. Symbols: w = weight, T = tension, n = normal reaction force, f = friction.

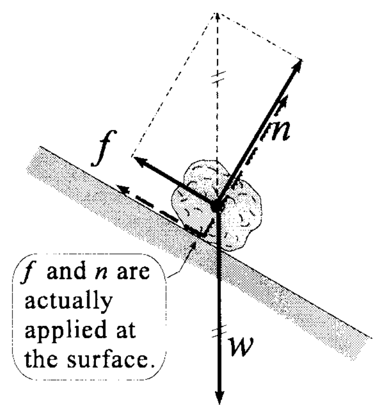
LM-1



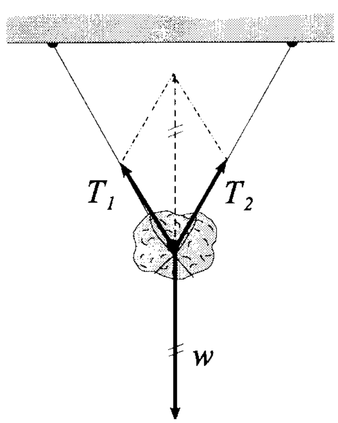
LM-2



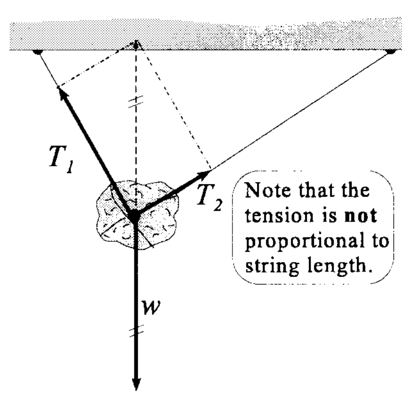
LM-3



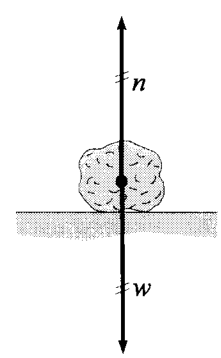
LM-4



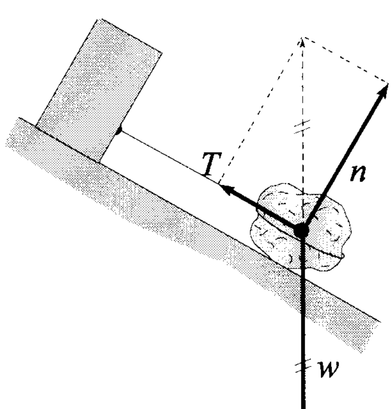
LM-5



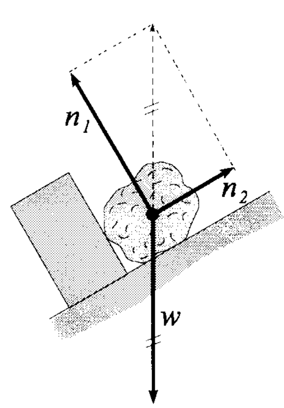
LM-6



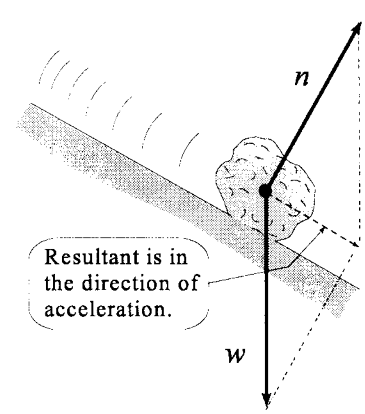
LM-7

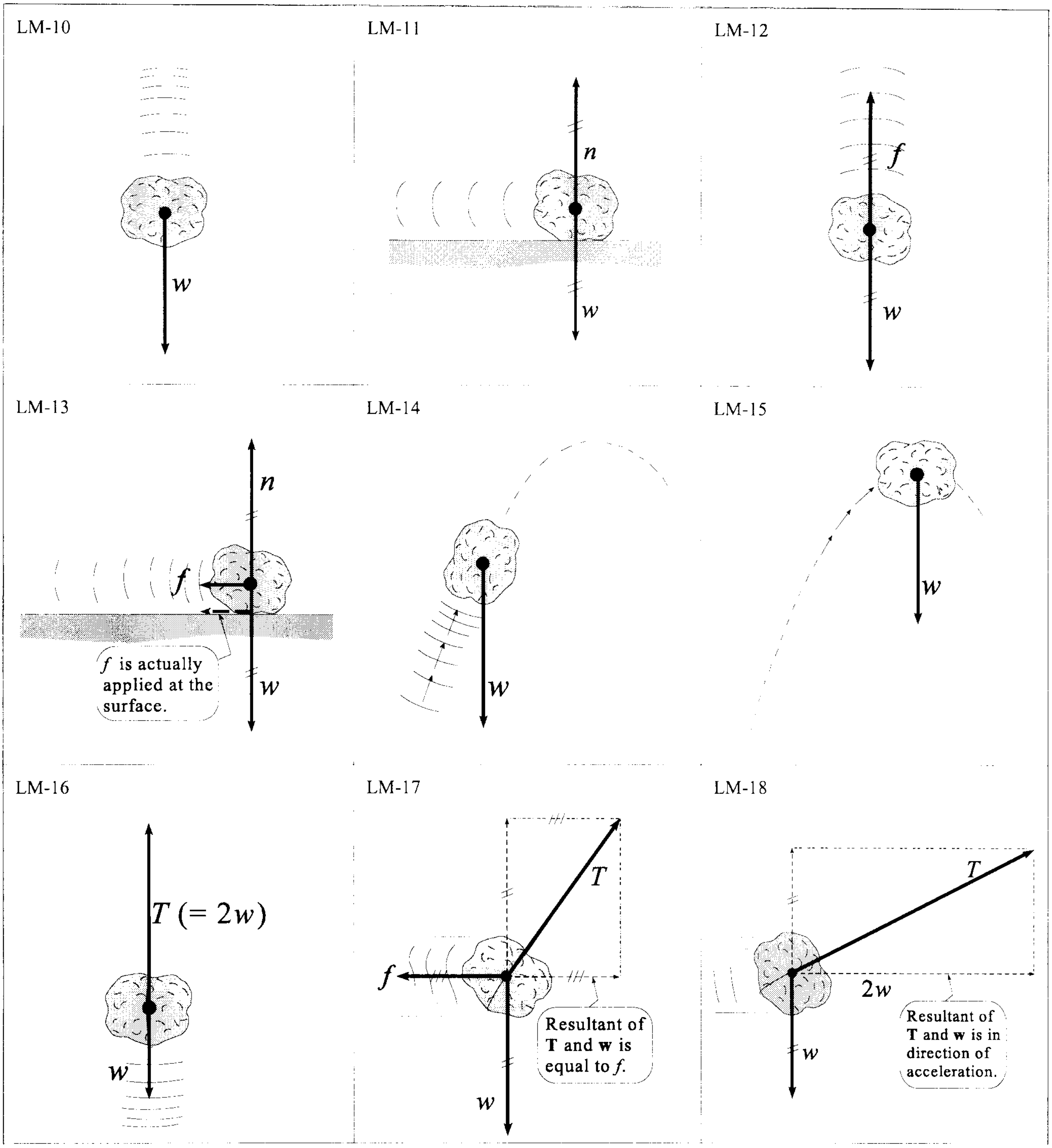


LM-8



LM-9

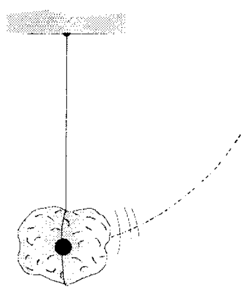



LM-10
w
LM-11
n
w
LM-12
f
w
LM-13
n
f
f is actually applied at the surface.
w
LM-14
w
LM-15
w
LM-16
T (= 2w)
w
LM-17
T
f
Resultant of T and w is equal to f.
w
LM-18
T
2w
w
Resultant of T and w is in direction of acceleration.

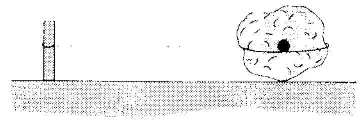
Free-Body Exercises: Circular Motion

Draw free-body diagrams showing forces acting on the rock, and in each case, indicate the centripetal force. Please note that the rock is **not** in equilibrium if it is moving in a circle. The centripetal force depends on angular velocity and there may not be any indication of exactly how big that force should be drawn. Symbols: w = weight, T = tension, f = friction, n = normal reaction force, F_c = centripetal force.

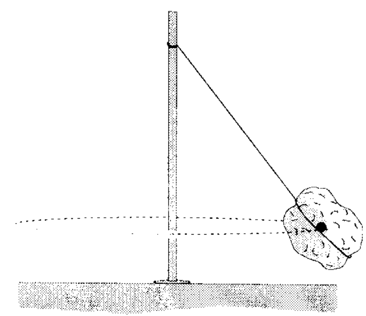
CM-1. Swinging on a rope, at lowest position. No friction.



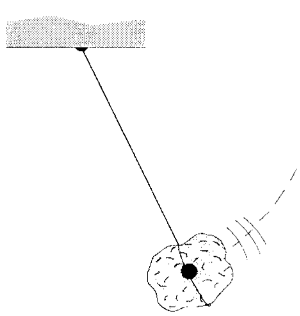
CM-2. Tied to a post and moving in a circle at constant speed on a frictionless horizontal surface. Moving straight out of the paper.



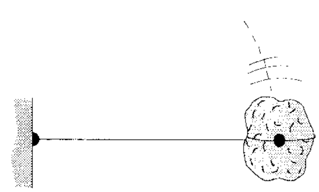
CM-3. String is tied to a post. Rock is moving toward you in a horizontal circle at constant speed. No friction.



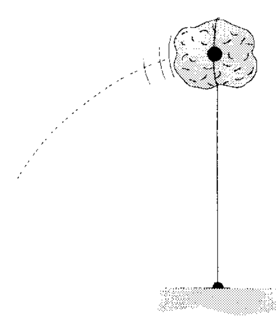
CM-4. Rock is swinging on a rope. No friction.



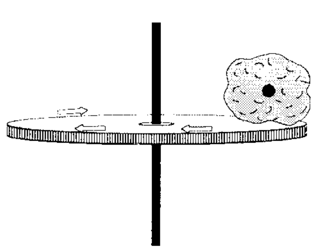
CM-5. Rock is moving downward in a vertical circle with the string horizontal.



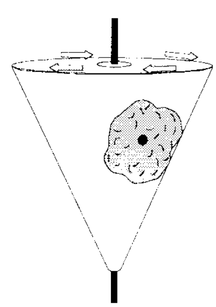
CM-6. Rock is swinging on a rope, at the top of a vertical circle. No friction.



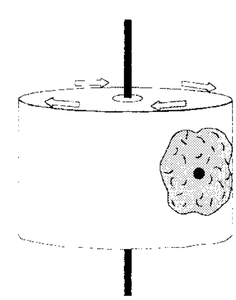
CM-7. Rock is riding on a horizontal disk that is rotating at constant speed about its vertical axis. Friction prevents rock from sliding. Rock is moving straight out of the paper.



CM-8. Rock is resting against the **frictionless** inside wall of a cone. It moves with the cone, which rotates about its vertical axis at constant angular speed.



CM-9. Rock is stuck by friction against the inside wall of a drum rotating about its vertical axis at constant speed. Rock is moving straight out of the paper.



Free-Body Solutions: Circular Motion

Symbols: w = weight, T = tension, f = friction, n = normal reaction force, F_c = centripetal force.