CHAPTER 5

FORCES IN EQUILIBRIUM

We have completed, for now, the study of kinematics. This will give us the basis for studying the movement of matter. Now we turn to forces, which *cause* the movement of matter we have studied.

A force is a difficult thing for a physicist to define because it is so fundamental that there are no terms more fundamental with which to explain it. Although a definition in terms of motion will be provided in the next chapter, for now it is probably best to just think of a force as you always have — a push or a pull on something. The units of force are familiar, pounds in the English system, and Newtons in the international system.

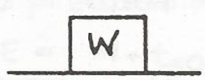
In this chapter we will study forces in equilibrium. That is, forces which balance each other out, or are equal in all directions. Here's a more technical way to say it: for any line passing through an object, the sum of all forces acting one way parallel to the line will be exactly balanced by the sum of the forces acting oppositely.

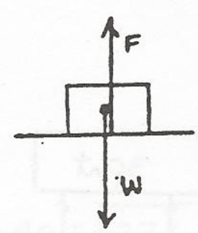
Think about it. For a body at rest this *has* to be true. If it weren't, there would be a greater force in one direction and the object would begin to accelerate.

In the following problems, sketch the diagrams and draw the forces acting on each object. Check frequently with the solutions so you will become familiar with the notation I use for various forces.

SOLUTIONS ↓

1. An object of weight W sits on a table.



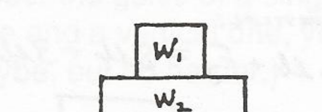


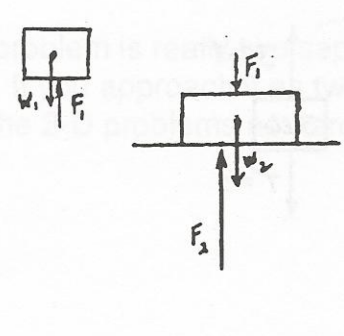
THE UPWARD FORCE OF TABLE BALANCES THE DOWNWARD FORCE OF GRAVITY.
$F = W$

2. An object of weight W hangs on a string.

AS BEFORE,
$T = W$
(THEY MUST BE EQUAL, OR THE WEIGHT WILL START TO ACCELERATE)

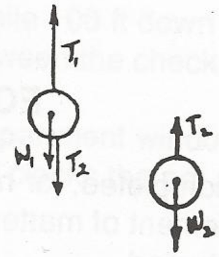
3. Two objects weighing W_1 and W_2 are stacked on a table.





$F_1 = W_1$
$F_2 = W_1 + W_2$

4. Two weights hang by a string.

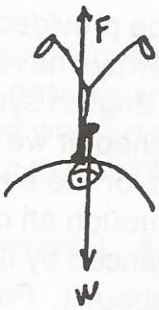


$W_2 = T_2$

$W_1 + W_2 = T_1$

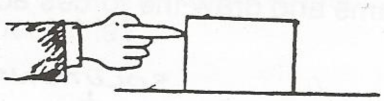
NOTE: T_2 PULLS UP ON W_2 AND DOWN ON W_1

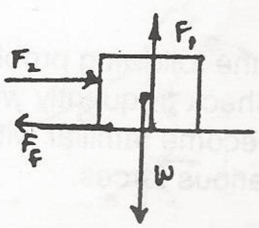
5. A skydiver falls at terminal velocity. (That is, air drag is enough to keep him from falling any faster.)



$W = F$

6. A block is pushed along a frictional table at constant speed.

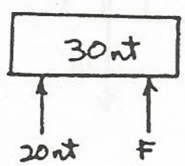




$F_2 = F_f$

$F_1 = W$

7. Find F.

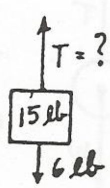


UP FORCES = DOWN FORCES

so $20nt + F = 30nt$

$F = \boxed{10nt}$

8. Find T.

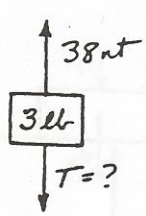


$T = 15lb + 6lb = \boxed{21lb}$

$38nt = (3lb)\left(\frac{4.45nt}{1lb}\right) + T$

$T = \boxed{24.7nt}$

9. Find T in newtons.



HORIZONTAL:

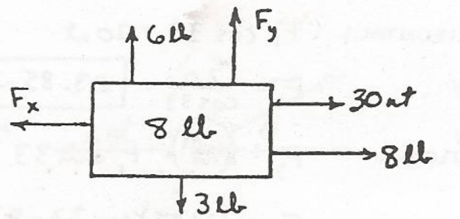
$F_x = (30nt)\left(\frac{1lb}{4.45nt}\right) + 8lb = \boxed{14.7lb}$

VERTICAL:

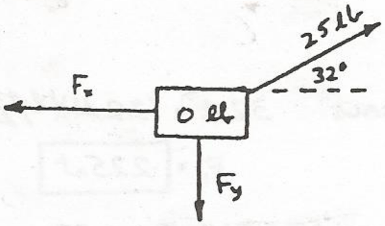
$6lb + F_y = 8lb + 3lb$

$F_y = \boxed{5lb}$

10. Find F_x and F_y.



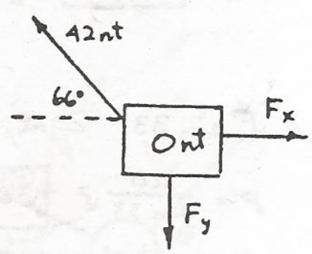
11. Find F_x and F_y.



$F_x = 25 \cos 32 = \boxed{21.2 \text{ lb}}$

$F_y = 25 \sin 32 = \boxed{13.3 \text{ lb}}$

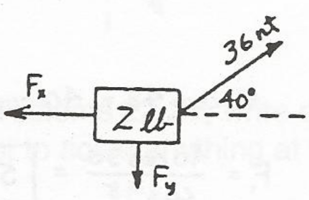
12. Find F_x and F_y.



$F_x = 42 \cos 66 = \boxed{17.1 \text{ nt}}$

$F_y = 42 \sin 66 = \boxed{38.4 \text{ nt}}$

13. Again, F_x and F_y in newtons.

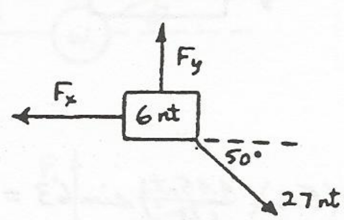


$F_x = 36 \cos 40 = \boxed{27.6 \text{ nt}}$

$F_y + (2 \text{ lb})\left(\frac{4.45 \text{ nt}}{1 \text{ lb}}\right) = 36 \sin 40$

So $F_y = \boxed{14.2 \text{ nt}}$

14. One last time, F_x and F_y.

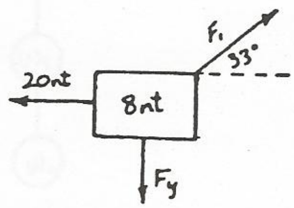


$F_x = 27 \cos 50 = \boxed{17.4 \text{ nt}}$

$F_y = 27 \sin 50 + 6 \text{ nt} = \boxed{26.7 \text{ nt}}$

As in kinematics, a two-dimensional problem is really two separate problems coexisting under the guise of a single problem. If you approach it as two problems — a horizontal one and a vertical one, you will find the 2-D problems no harder than 1-D. (More complex, maybe, but no harder.)

15. First find F_1, then find F_y.



HORIZONTAL: $F_1 \cos 33 = 20\,nt$

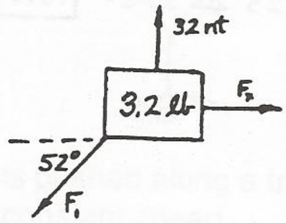
$F_1 = \frac{20}{\cos 33} = \boxed{23.85\,nt}$

VERTICAL: $F_y + 8\,nt = F_1 \sin 33$

$F_y = (23.85) \sin 33 - 8$

$= \boxed{5.0\,nt}$

16. Again, F_1 and then F_x.



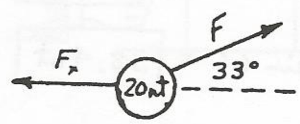
VERTICAL: $32\,nt = (3.2\,lb)\left(\frac{4.45\,nt}{1\,lb}\right) + F_1 \sin 52$

$F_1 = \boxed{22.5\,nt}$

HORIZONTAL: $F_x = F_1 \cos 52$

$= \boxed{13.9\,nt}$

17. Keep at it.

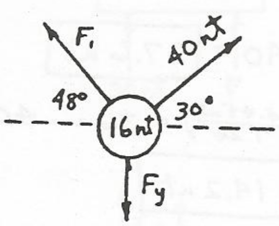


VERTICAL: $F \sin 33 = 20\,nt$

$F = \frac{20}{\sin 33} = \boxed{36.7\,nt}$

HORIZONTAL: $F_x = F \cos 33 = \boxed{30.8\,nt}$

18*. Find F_1 and F_y.



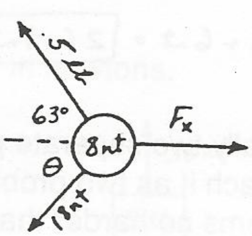
HORIZONTAL: $F_1 \cos 48 = 40 \cos 30$

$F_1 = \frac{40 \cos 30}{\cos 48} = \boxed{51.8\,nt}$

VERTICAL: $F_1 \sin 48 + 40 \sin 30 = 16 + F_y$

$F_y = \boxed{42.5\,nt}$

19*. Find F_x and θ.



VERTICAL: $(5\,lb)\left(\frac{4.45\,nt}{1\,lb}\right) \sin 63 = 8 + 18 \sin\theta$

$\sin\theta = \frac{(5)(4.45)\sin 63 - 8}{18} = .657$

$\theta = \boxed{41.1^\circ}$

HORIZONTAL: $F_x = (5)(4.45)\cos 63 + 18 \cos\theta$

$= \boxed{23.7\,nt}$