Let's first start which problem 8.2.2, and discuss the general idea of torque.

Torque is a vector, and it is defined as r cross F. I have to be a little bit more specific: the torque is always relative to a point. Let's assume that there is a force here, then the definition of the torque relative to this point-- this is the position vector, so to speak, measured from P-- then the torque relative to point P is the cross product between r, this vector, and F. If this angle equals theta, then the magnitude of the torque-- not talking about the direction-- equals the magnitude of r times the magnitude of F times the sine of theta.

As far as the direction is concerned, it is always perpendicular to both F and to r, so it's perpendicular to the plane of the paper. In this case, if you remember how to apply the rule of cross product, the torque vector is in the paper, which we would indicate with a circle ma cross. You're looking at the tail of an arrow that went into the paper. If it were out of the paper, then I would indicate it with a circle with a dot-- you'd see the tip of the arrow.

The torque can be positive or can be negative-- you can see that immediately, depending upon the sign of sine theta. If I had a point Q here, then torque relative to point Q would be negative, and so the torque would be coming out of the paper. In our case, the torque P is larger than 0, and you can have torques relative to points which are 0.

For instance, if I draw a line here, an extension of what I called the working line-- in high school, I was taught that the line along which the force acts is called the working line. Any point A that you have-- it doesn't matter whether you have it here, or here, or here-- it's immediately obvious that the torque is 0, because r sine theta, which is this distance, I call it often r perpendicular. You should really be convincing yourself that is r sine theta, and so for all these points A on this line, r sine theta equals 0, and so the torque is 0.

If I chose a line perpendicular to F, perpendicular to this working lines, and I had here a point P 1, a point P 2, and a point P 3, then the torque relative to point P would be the torque relative to point P 1, would be the torque relative to point P 2, and so on. First of all, the torque is always positive-- and the simple reason is that r is perpendicular and the same for all these points. I hope that this will help you a little bit in getting going on this problem.

Now I want to address some special cases. Let us suppose that we have that F 2 equals F 3, and that they are parallel. Here I have a point P, here I have a force F 2, and here I have a force F 3. It doesn't have to be exactly going through this point-- by the way, this distance is the same as this distance. I could have a force here of F 3, same in magnitude, and just to make it even a little bit more complicated, why don't I also have a force by the work line that goes straight through point P.

It should be obvious now to you that the next torque relative to point P equals 0. If I think of the torque P due to force 2, it would give me a rotation-- it is a clockwise rotation-- the torque would be larger than 0. You can immediately see that all three, if F 3 and F 2 have the same magnitude, is a counterclockwise rotation, it is negative-- the torque-- and the two cancel each other. F 1 goes straight through F, so our perpendicular is 0, and so clearly there is no contribution to the torque due to F 1.

I want you to notice, though, that the sum of all forces is not 0. Here we have a situation that the sum of all torques is 0, but that the sum of all forces is not 0. If these forces acted on an object of which P was the center of mass-- it was some kind of an object, and P was the center of mass-- then there would be no rotation, but this point P would undergo a pure translation. The whole object would undergo a pure translation with constant acceleration along a straight line.

Now the question comes: is it possible that sum of all forces is 0, but that the sum of all torques is not 0? Of course, that is also possible, and I'll show you an example of that. The sum of all forces is 0, but now the sum of all torques is not 0.

Suppose we have here point P-- this distance is the same as this distance--- I have a force F 1, which is in this direction, and I have a force F 2, which in magnitude the same. It acts along a line, which is parallel to the working line of F 1, and the force is here, F 2. The torque 1, P, was this point, is positive and it's clockwise, the torque too is also clockwise, so there is clearly going to be a rotation. There's no way around it, yet the sum of all forces is 0.

You see according to Newton's Law, which says that the sum of all forces total equals m times a total. This is 0, so there's no acceleration. It's only going to rotate, but it's not going to translate. In this specific case, no matter where you choose a point A, or Q, or B-- this is a very special case-- you can easily prove that the torque relative to point P, the torque, is exactly the same as the torque relative to point Q, and is exactly the same as the torque relative to point A, no matter where you put them.

The magnitude of that torque-- of course, the torque is in the paper, it's a clockwise rotation-- if I call this separation between the two l, then the magnitude of that torque, no matter which one you take, would be F 1 times l. F 1 is, of course, also in magnitude is the same as F 2. That's a very special cases.

Torques are key in rotation, and we will see several examples of that today.