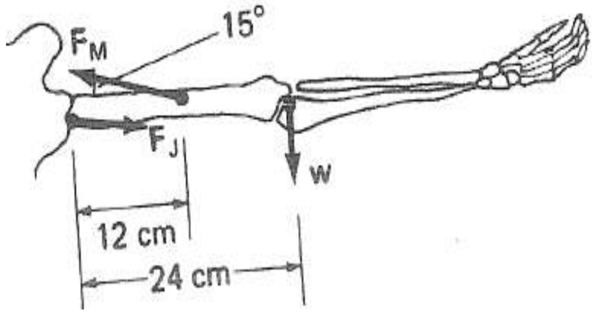
Q- (a) Calculate the force required in the deltoid muscle (F_m) to hold up the outstretched arm as shown in the figure. The mass of the arm is 2.8 kg.
(b) What is the muscle force and the reaction Fj at joint if the hand holds a ball of mass 5 kg at a distance 50 cm from the shoulder joint?

(a) The rotational effect of a force is called torque or moment of the force and is given by $\vec{\tau} = \vec{r} \times \vec{F}$



Here r the radius vector to the point of application of the force and the magnitude will be

$$\tau = r * F * \sin\theta$$

Considering the shoulder joint as the point of rotation and taking moment of the forces about this point we have
Torque due to weight w will be

$$\tau_1 = -r_1 * W * \sin 90^0 = -0.24 * (2.8 * 9.8) * 1.0 = -6.586 \text{ Nm.}$$

The negative sign is due to the torque is clockwise.
Similarly torque due to the force in deltoid muscle F_m will be

$$\tau_2 = r_2 * F_m * \sin 15^0 = 0.12 * F_m * 0.259 = 0.031 F_m \text{ Nm. (anticlockwise)}$$

As the arm is in equilibrium, the net torque acting on it must be zero hence we have

$$\tau_1 + \tau_2 = 0$$

Gives - 6.586 + 0.031 F_m = 0
Or F_m = 6.586/0.031 **= 212.45 N**

(b) In case when there is a ball in the arm, there will be a third torque will act due to the weight of the ball and this will be given by

$$\tau_3 = -r_3 * mg * \sin 90^0 = -0.50 * (5.0 * 9.8) * 1.0 = -24.5 \text{ Nm.}$$

This extra torque will be balanced by the increase in the force in the deltoid muscle let it is now F' then again for equilibrium we have

$$\tau_1 + \tau'_2 + \tau_3 = 0$$

Or - 6.586 + 0.031 F'_m – 24.5 = 0

Gives F'_m **=** 1005.96 N.

The force Fj on the shoulder joint is balancing the component of the F'm in the horizontal direction and hence

Fj = F'm cos 15^0 = 1005.96*0.966 **= 971.76 N**