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 \(F_j\) 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 \(\vec{r}\) the radius vector to the point of application of the force and the magnitude will be
\[ \tau = r \times F \times \sin \theta \]

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
\[ \tau_1 = -r_1 \times W \times \sin 90^\circ = -0.24 \times (2.8 \times 9.8) \times 1.0 = -6.586 \text{ Nm}. \]

The negative sign is due to the torque is clockwise.
Similarly torque due to the force in deltoid muscle \(F_m\) will be
\[ \tau_2 = r_2 \times F_m \times \sin 15^\circ = 0.12 \times F_m \times 0.259 = 0.031 F_m \text{ Nm. (anticlockwise)} \]

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 \(F_m = 6.586/0.031 = 212.45 \text{ N}\)

(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
\[ \tau_3 = -r_3 \times mg \times \sin 90^\circ = -0.50 \times (5.0 \times 9.8) \times 1.0 = -24.5 \text{ Nm}. \]

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 \(F'_m = 1005.96 \text{ N}\).

The force \(F_j\) on the shoulder joint is balancing the component of the \(F'm\) in the horizontal direction and hence
\[ F_j = F'_m \cos 15^\circ = 1005.96 \times 0.966 = 971.76 \text{ N} \]