10.0 ml of a 0.30 M sodium phosphate solution reacts with 20.0 ml of a 0.20 M lead (II) nitrate solution (assume no volume change). What is the concentration of nitrate and phosphate ions left in solution after the reaction is complete?

Solution: Let us write the molecular and ion chemical reaction equations between sodium phosphate and lead (II) nitrate:

$$2Na_3PO_4 + 3Pb(NO_3)_2 \rightarrow 6NaNO_3 + Pb_3(PO_4)_2\downarrow$$

$$6Na^+ + 2PO_4^{3-} + 3Pb^{2+} + 6NO_3^- \rightarrow 6Na^+ + 6NO_3^- + Pb_3(PO_4)_2\downarrow$$

$$2PO_4^{3-} + 3Pb^{2+} \rightarrow Pb_3(PO_4)_2\downarrow$$

As it is known, lead (II) phosphate is completely insoluble in the water, so it precipitates.

From the equation you can see, that nitrate ions are staying in the solution without changing their amount, while phosphate ions are becoming a part of insoluble lead (II) phosphate, and transferring from solution into solid phase.

First, we must find, which reagent is in deficiency. To do this, we must compare initial substance amounts of sodium phosphate and lead (II) nitrate:

$n(Na_3PO_4) = V(Na_3PO_4)\cdot C(Na_3PO_4)/1000 = 10\cdot 0.3/1000 = 0.003$ mole;

$n(Pb(NO_3)_2) = V(Pb(NO_3)_2)\cdot C(Pb(NO_3)_2)/1000 = 20\cdot 0.2/1000 = 0.004$ mole;

According to the equation, 2 moles of sodium phosphate completely react with 3 moles of lead (II) nitrate. Then, $n(Na_3PO_4)/2 = 0.0015$ mole; $n(Pb(NO_3)_2)/3 = 0.00133$ mole;

Comparing these two amounts, we can see that lead (II) nitrate is in deficiency, which means, it will fully react and become a lead (II) phosphate.

Concentration of nitrate ions after the reaction will be:

$$C'(NO_3^-) = \frac{2\cdot n(Pb(NO_3)_2)\cdot 1000}{V(Pb(NO_3)_2) + V(Na_3PO_4)} = \frac{2\cdot 0.004\cdot 1000}{10+20} = 0.267\,M;$$

After the reaction there will be left such amount of the sodium phosphate in the solution:

$n'(Na_3PO_4) = n(Na_3PO_4)\cdot - n(Pb(NO_3)_2)\cdot 2/3 = 0.003 - 0.004\cdot 2/3 = 0.000333$ mole;

Then, concentration of phosphate ions after the reaction will be:

$$C'(PO_4^{3-}) = \frac{n'(Na_3PO_4)\cdot 1000}{V(Pb(NO_3)_2) + V(Na_3PO_4)} = \frac{0.000333\cdot 1000}{10+20} = 0.0111\,M;$$

Answer: After the reaction is complete in solution will be 0.267 M of nitrate ions and 0.0111 M of phosphate ions.