Aspirin, C9H8O4, is produced from salicylic acid, C7H6O3, and acetic anhydride, C4H6O3, as shown below.
C7H6O3 + C4H6O3 C9H8O4 + HC2H3O2

(a) How much salicylic acid is required to produce 3.1 102 kg of aspirin, assuming that all of the salicylic acid is converted to aspirin?

kg

(b) How much salicylic acid would be required if only 61% of the salicylic acid is converted to aspirin?

kg

(c) What is the theoretical yield of aspirin if 193 kg of salicylic acid is allowed to react with 159 kg of acetic anhydride?

kg

(d) If the situation described in part (c) produces 189 kg of aspirin, what is the percentage yield?

%

Solution

$C_7H_6O_3 + C_4H_6O_3 \longrightarrow C_9H_8O_4 + C_2H_4O_2$

a) Find chemical amount of aspirin:
   n = m/M;
   $M(C_9H_8O_4) = 12\cdot9+1\cdot8+16\cdot4 = 180$ (g/mol);
   $m(C_9H_8O_4) = 3.1102$ kg =3110.2 g
   $n(C_9H_8O_4) = 3110.2 / 180 = 17.3$ (mole).

   According to equation 1 mole of salicylic acid gives 1 mole of aspirin.
   $n(C_9H_8O_4) = n(C_7H_6O_3)$;
   $n(C_7H_6O_3) = 17.3$ mole.

   Find mass of salicylic acid:
   m= M·n;
   $M(C_7H_6O_3) = 12\cdot7+1\cdot6+16\cdot3 = 138$ (g/mol);
   $m(C_7H_6O_3) = 138\cdot17.3 = 2387.4$ g = 2.3874 kg.

b) $\eta = m_{actual}/m_{theoretical}$;
$m_{theoretical} = m_{actual}/\eta$.
$m_{actual}(C_7H_6O_3) = 2.3874$ kg;
$m_{theoretical}(C_7H_6O_3) = 2.3874/0.61 = 3.9138$ (kg).

c) Find chemical amount of salicylic acid:
$n = m/M$;
$M(C_7H_6O_3) = 138$ g/mol;
$m(C_7H_6O_3) = 193$ kg $=193000$ g
$n(C_7H_6O_3) =193000 / 138 = 1398.6$ (mole).

Find chemical amount of acetic anhydride:
$n = m/M$;
$M(C_4H_6O_3) = 12\cdot4+1\cdot6+16\cdot3 = 102$ g/mol;
$m(C_4H_6O_3) = 159$ kg $=159000$ g
$n(C_4H_6O_3) =159000 / 102 = 1558.8$ (mole).

According to equation 1 mole of salicylic acid reacts with 1 mole of acetic anhydride, i.e.
$n(C_7H_6O_3) = n(C_4H_6O_3)$.
We have $n(C_7H_6O_3) = 1398.6$ mole and $n(C_4H_6O_3) = 1558.8$ mole.
$n(C_7H_6O_3) < n(C_4H_6O_3)$;
$1398.6 < 1558.8$.
Salicylic acid is a limiting reactant.

Find chemical amount of aspirin:
according to equation 1 mole of salicylic acid gives 1 mole of aspirin.
$n(C_7H_6O_3) = n(C_9H_8O_4)$;
$n(C_9H_8O_4) = 1398.6$ mole.
$m = n\cdot M$;
$M(C_9H_8O_4) = 180$ g/mol;
$m(C_9H_8O_4) = 1398.6\cdot180 = 251748$ (g);
$m(C_9H_8O_4) = 251.748$ kg.

d) $\eta = m_{actual}/m_{theoretical}$;
$\eta = 189/251.748 = 0.75$ or 75%.

Answer:

a) 2.3874 kg;
b) 3.9138 kg;
c) 251.748 kg;
d) 75%.