1. [4] Consider program P, which runs on a 1 GHz machine M in 10 seconds. An optimization is made to P, replacing all instances of multiplying a value by 4 (mult X, X, 4) with two instructions that set x to x+x twice (add X, X; add X,X). Call this new optimized program as Q. The CPI of a multiply instruction is 4, and the CPI of an add is 1. After recompiling, the program runs in 9 seconds on machine M. How many multiplies were replaced by the new compiler?

\[
\text{CPU time}_P - \text{CPU time}_Q = 1 \text{ sec} \\
N_{\text{mult}} \left( \frac{\text{CPI}_{\text{mult}} - \text{CPI}_{\text{add}}}{4} \right) \times \text{clock cycle time} = 1 \text{ sec} \\
2 \times 10^{-9} \\
N_{\text{mult}} = \frac{10^{-9}}{2} = 5 \times 10^8
\]

2. [6] You are going to enhance a computer, and there are two possible improvements: either make multiply instructions run four times faster than before, or make memory access instructions run two times faster than before. You repeatedly run a program that takes 100 seconds to execute. Of this time, 20% is used for multiplication, 50% for memory access instructions, and 30% for other tasks.

   a. What will the speedup be if you improve only multiplication?

\[
\text{Speedup}_{\text{mult}} = \frac{1}{0.8 + 0.2/4} = 1.17 \\
\text{Speedup}_{\text{mult}} = \frac{\text{Exectime old}}{\text{Exectime new}} = 9
\]

   b. What will the speedup be if you improve only memory access?

\[
\text{Speedup}_{\text{ma}} = \frac{1}{0.8 + 0.5/2} = 1.33
\]

   c. What will the speedup be if both improvements are made?

\[
\text{Speedup}_{\text{overall}} = \frac{\text{Exectime old}}{\text{Exectime new}} = \frac{100}{80} = 1.25
\]