Consider a programming language that consists of commands \( C \) composed from assignments \( V := E \) (where \( E \) is an expression) using sequences \( C_1 ; C_2 \), conditionals \( \text{IF } S \text{ THEN } C_1 \text{ ELSE } C_2 \) (where \( S \) is a statement) and while-loops \( \text{WHILE } S \text{ DO } C \).

(a) Carefully explain the meaning of total correctness Hoare triples. [2 marks]

(b) Suggest a command \( C \) such that the following partial correctness triple holds.

\[
\{ X = x \} \ C \ \{ 1 = 2 \}
\]

Explain why the triple holds. [4 marks]

(c) Consider Hoare triples of the form \( \{ P \} \ X := E \ \{ P[E/X] \} \) where \( P \), \( X \) and \( E \) range over formulas, variables and expressions, respectively. Recall that \( P[E/X] \) denotes \( P \) with \( E \) substituted for every occurrence of \( X \) in \( P \).

Write down an instance of such a triple that cannot be proved using Hoare logic and explain why it cannot be proved. [4 marks]

(d) Write down a partial correctness specification for a command that adds the initial values stored in variables \( X \) and \( Y \). The command should store the result in a variable \( Z \). [4 marks]

(e) Propose a loop invariant for proving the following partial correctness triple.

\[
\{ X = n \land Y = 0 \land n \geq 0 \}
\]

\[
\text{WHILE } X > 0 \text{ DO } (Y := Y + X; \ X := X - 1)
\]

\[
\{ Y = \sum_{i=1}^{n} i \}
\]

[6 marks]