1.a

Table 11.1 Requirements for a Cryptographic Hash Function H

Requirement	Description
Variable input size	H can be applied to a block of data of any size.
Fixed output size	H produces a fixed-length output.
Efficiency	H(x) is relatively easy to compute for any given x, making both hardware and software implementations practical.
Preimage resistant (one-way property)	For any given hash value h, it is computationally infeasible to find y such that $H(y) = h$.
Second preimage resistant (weak collision resistant)	For any given block x, it is computationally infeasible to find $y \neq x$ with $H(y) = H(x)$.
Collision resistant (strong collision resistant)	It is computationally infeasible to find any pair (x, y) such that $H(x) = H(y)$.
Pseudorandomness	Output of H meets standard tests for pseudorandomness.

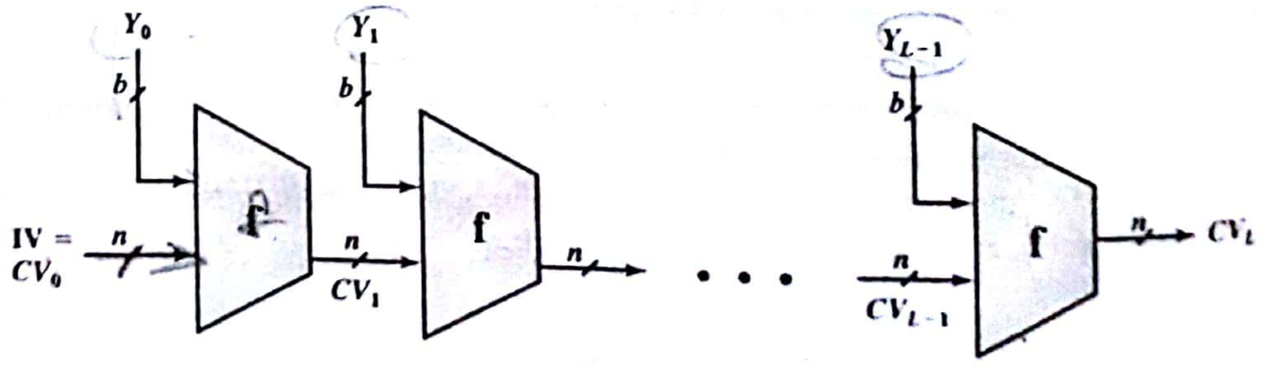
time would be much shorter, so that 100 bits now app

1.b Cryptanalysis

As with encryption algorithms, cryptanalytic attacks on hash functions seek to exploit some property of the algorithm to perform some attack other than an exhaustive search. The way to measure the resistance of a hash algorithm to cryptanalysis is to compare its strength to the effort required for a brute-force attack. That is, an ideal hash algorithm will require a cryptanalytic effort greater than or equal to the brute-force effort.

In recent years, there has been considerable effort, and some successes, in developing cryptanalytic attacks on hash functions. To understand these, we need to look at the overall structure of a typical secure hash function, indicated in Figure 11.7. This structure, referred to as an iterated hash function, was proposed by Merkle [MERK79, MERK89] and is the structure of most hash functions in use today, including SHA, which is discussed later in this chapter. The hash function takes an input message and partitions it into L fixed-sized blocks of b bits each. If necessary, the final block is padded to b bits. The final block also includes the value of the total length of the input to the hash function. The inclusion of the length makes the job of the opponent more difficult. Either the opponent must find two messages of equal length that hash to the same value or two messages of differing lengths that, together with their length values, hash to the same value.

The hash algorithm involves repeated use of a **compression function** f, that takes two inputs (an n-bit input from the previous step, called the *chaining variable*, and a b-bit block) and produces an n-bit output. At the start of hashing, the chaining variable has an initial value that is specified as part of the algorithm. The final value



IV	= Initial value	L	= Number of input blocks
CV_i	= Chaining variable	n	= Length of hash code
Y_i	= ith input block	b	= Length of input block
f	= Compression algorithm		

Figure 11.7 General Structure of Secure Hash Code

of the chaining variable is the hash value. Often, $b > n$; hence the term *compression*. The hash function can be summarized as

$$\begin{aligned} CV_0 &= IV = \text{initial } n\text{-bit value} \\ CV_i &= \mathrm{f}(CV_{i-1}, Y_{i-1}) \quad 1 \le i \le L \\ \mathrm{H}(M) &= CV_L \end{aligned}$$

where the input to the hash function is a message M consisting of the blocks $Y_0, Y_1, \ldots, Y_{L-1}$.

The motivation for this iterative structure stems from the observation by Merkle [MERK89] and Damgard [DAMG89] that if the compression function is collision resistant, then so is the resultant iterated hash function.[1] Therefore, the structure can be used to produce a secure hash function to operate on a message of any length. The problem of designing a secure hash function reduces to that of designing a collision-resistant compression function that operates on inputs of some fixed size.

Cryptanalysis of hash functions focuses on the internal structure of f and is based on attempts to find efficient techniques for producing collisions for a single execution of f. Once that is done, the attack must take into account the fixed value of IV. The attack on f depends on exploiting its internal structure. Typically, as with symmetric block ciphers, f consists of a series of rounds of processing, so that the attack involves analysis of the pattern of bit changes from round to round.

Keep in mind that for any hash function there must exist collisions, because we are mapping a message of length at least equal to twice the block size b (because we must append a length field) into a hash code of length n, where $b \geq n$. What is required is that it is computationally infeasible to find collisions.

The attacks that have been mounted on hash functions are rather complex and beyond our scope here. For the interested reader, [DOBB96] and [BELL97] are recommended.

11.4 SH FUNCTIONS BASED ON CIPHER BLOCK CHAINING