tool. Therefore, one does not have to accumulate years of experience in order to become a productive designer of digital circuits; nor does one have to first acquire an extensive background in electrical engineering.

There is no difference between a state table and a state diagram, except in the manner of representation. The state table is easier to derive from a given logic diagram and the state equation. The state diagram follows directly from the state table. *The state diagram gives a pictorial view of state transitions and is the form more suitable for human interpretation of the circuit's operation*. For example, the state diagram of **Fig. 5.16** clearly shows that, starting from state 00, the output is 0 as long as the input stays at 1. The first 0 input after a string of 1's gives an output of 1 and transfers the circuit back to the initial state, 00. The machine represented by this state diagram acts to detect a zero in the bit stream of data. It corresponds to the behavior of the circuit in **Fig. 5.15**. Other circuits that detect a zero in a stream of data may have a simpler circuit diagram and state diagram.

Flip-Flop Input Equations

The logic diagram of a sequential circuit consists of flip-flops and gates. The interconnections among the gates form a combinational circuit and may be specified algebraically with Boolean expressions. The knowledge of the type of flip-flops and a list of the Boolean expressions of the combinational circuit provide the information needed to draw the logic diagram of the sequential circuit. The part of the combinational circuit that generates external outputs is described algebraically by a set of Boolean functions called *output equations*. The part of the circuit that generates the inputs to flip-flops is described algebraically by a set of Boolean functions called flip-flop *input equations* (or, sometimes, *excitation equations*). We will adopt the convention of using the flip-flop input symbol to denote the input equation variable and a subscript to designate the name of the flip-flop output. For example, the following input equation specifies an OR gate with inputs *x* and *y* connected to the *D* input of a flip-flop whose output is labeled with the symbol *Q*:

$$D_Q = x + y$$

The sequential circuit of **Fig. 5.15** consists of two *D* flip-flops *A* and *B*, an input *x*, and an output *y*. The logic diagram of the circuit can be expressed algebraically with two flip-flop input equations and an output equation:

$$\begin{aligned} D_A &= Ax + Bx \\ D_B &= A'x \\ y &= (A + B)x' \end{aligned}$$

The three equations provide the necessary information for drawing the logic diagram of the sequential circuit. The symbol D_A specifies the data input of a *D* flip-flop labeled *A*. D_B specifies the data input of a second *D* flip-flop labeled *B*. The Boolean expressions associated with these two variables and the expression for output *y* specify the combinational circuit part of the sequential circuit.

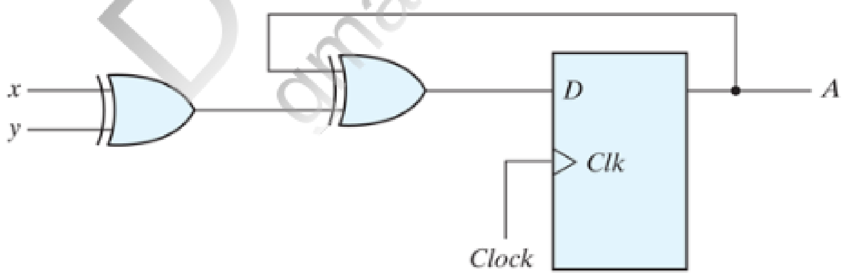
The flip-flop input equations constitute a convenient algebraic form for specifying the logic diagram of a sequential circuit. They imply the type of flip-flop from the letter symbol, and they fully specify the combinational circuit that drives the flip-flops. Note that the expression for the input equation for a *D* flip-flop is identical to the expression for the corresponding state equation. This is because of the characteristic equation that equates the next state to the value of the *D* input: $Q(t+1) = D_Q$.

Analysis with *D* Flip-Flops

We will summarize the procedure for analyzing a clocked sequential circuit with *D* flip-flops by means of a simple example. The circuit we want to analyze is described by the input equation

$$D_A = A \oplus x \oplus y$$

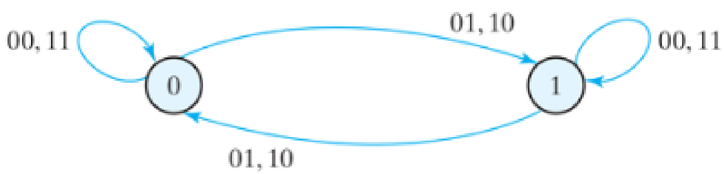
The D_A symbol implies a *D* flip-flop with output *A*. The *x* and *y* variables are the inputs to the circuit. No output equations are given, which implies that the output comes from the output of the flip-flop. The logic diagram is obtained from the input equation and is drawn in **Fig. 5.17(a)**.



(a) Circuit diagram

Present state	Inputs		Next state
A	*x*	*y*	*A*
0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	0
1	0	0	1
1	0	1	0
1	1	0	0
1	1	1	1

(b) State table



(c) State diagram

FIGURE 5.17

Sequential circuit with *D* flip-flop

The state table has one column for the present state of flip-flop *A*, two columns for the two inputs, and one column for the next state of *A*. The binary numbers under