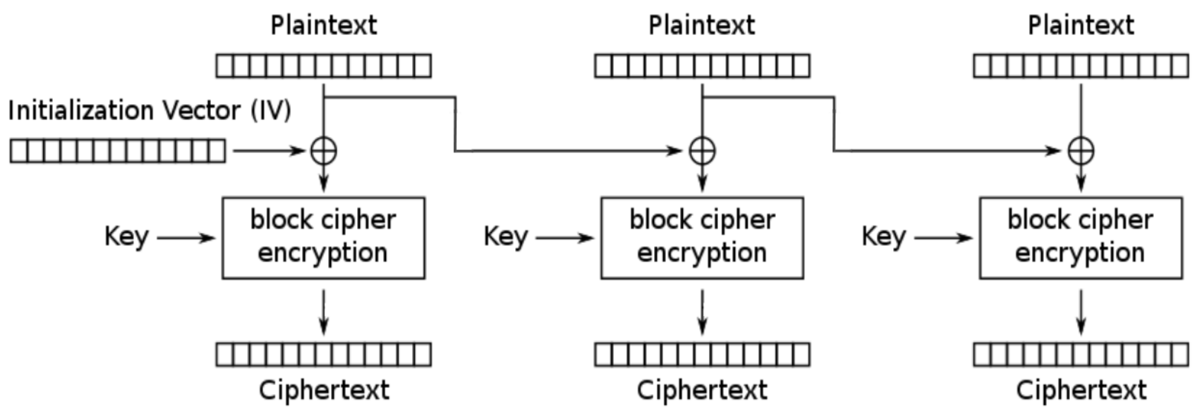
Q1 *Block Ciphers* (0 points)

Consider the following block cipher mode of operation.

M_i is the ith plaintext block. C_i is the ith ciphertext block. E_K is AES encryption with key K.

$$C_0 = M_0 = IV$$
$$C_i = E_K(M_{i-1} \oplus M_i)$$



Q1.1 Which of the following is true about this scheme? Select all that apply.

☐ (A) The encryption algorithm is parallelizable

☐ (B) If one byte of a plaintext block M_i is changed, then the corresponding ciphertext block C_i will be different in exactly one byte

☐ (C) If one byte of a plaintext block M_i is changed, then the next ciphertext block C_{i+1} will be different in exactly one byte

☐ (D) If two plaintext blocks are identical, then the corresponding ciphertext blocks are also identical

☐ (E) The encryption algorithm requires padding the plaintext

☐ (F) None of the above

Q1.2 True or False: If the IV is always a block of all 0s for every encryption, this scheme is IND-CPA secure. Briefly justify your answer.

○ (G) True ○ (H) False ○ (I) —— ○ (J) —— ○ (K) —— ○ (L) ——

Q1.3 True or False: If the IV is randomly generated for every encryption, this scheme is IND-CPA secure. Briefly justify your answer.

○ (A) True ○ (B) False ○ (C) —— ○ (D) —— ○ (E) —— ○ (F) ——

Q2 *IV-e got a question for ya* **(0 points)**

Determine whether each of the following schemes is IND-CPA secure. This question has 6 subparts.

Q2.1 AES-CBC where the IV for message M is chosen as HMAC-SHA256(k_2, M) truncated to the first 128 bits. The MAC key k_2 is distinct from the encryption key k_1.

Provide a short justification for your answer on your answer sheet.

- (A) Insecure
- (B) Secure
- (C) —
- (D) —
- (E) —
- (F) —

Q2.2 AES-CTR where the IV for message M is chosen as HMAC-SHA256(k_2, M) truncated to the first 128 bits. The MAC key k_2 is distinct from the encryption key k_1.

Provide a short justification for your answer on your answer sheet.

Clarification made during the exam: You can assume that IV refers to the nonce for CTR mode.

- (G) Insecure
- (H) Secure
- (I) —
- (J) —
- (K) —
- (L) —

Q2.3 AES-CBC where the IV for message M is chosen as SHA-256(x) truncated to the first 128 bits. x is a predictable counter starting at 0 and incremented *per message*.

- (A) Insecure
- (B) Secure
- (C) —
- (D) —
- (E) —
- (F) —

Q2.4 AES-CTR where the IV for message M is chosen as SHA-256(x) truncated to the first 128 bits. x is a predictable counter starting at 0 and incremented *per message*.

Clarification made during the exam: You can assume that IV refers to the nonce for CTR mode.

- (G) Insecure
- (H) Secure
- (I) —
- (J) —
- (K) —
- (L) —

Q2.5 AES-CBC where the IV for message M is chosen as HMAC-SHA256$(k_2 + x, M)$ truncated to the first 128 bits. The MAC key k_2 is distinct from the encryption key k_1 and x is a predictable counter starting at 0 and incremented *per message*.

- (A) Insecure
- (B) Secure
- (C) —
- (D) —
- (E) —
- (F) —

Q2.6 AES-CTR where the IV for message M is chosen as HMAC-SHA256$(k_2 + x, M)$ truncated to the first 128 bits. The MAC key k_2 is distinct from the encryption key k_1 and x is a predictable counter starting at 0 and incremented *per message*.

Clarification made during the exam: You can assume that IV refers to the nonce for CTR mode.

- (G) Insecure
- (H) Secure
- (I) —
- (J) —
- (K) —
- (L) —

Q3 *Encryption and Authentication* **(0 points)**

Alice wants to send messages to Bob, but Mallory (a man-in-the-middle attacker) will read and tamper with data sent over the insecure channel.

- Alice and Bob share two secret keys K_1 and K_2
- K_1 and K_2 have not been leaked (Alice and Bob are the only people who know the keys)
- Enc is an IND-CPA secure encryption scheme
- MAC is a secure (unforgeable) MAC scheme

For each cryptographic scheme, select all true statements.

Clarification during exam: For the answer choice "Bob can always recover the message M," assume that Mallory has not tampered with the message.

Clarification during exam: The answer choice "Bob can guarantee that M has not been changed by Mallory," this should say "Bob can guarantee that M has not been changed by Mallory without detection."

Q3.1 $\mathsf{Enc}(K_1, M), \mathsf{MAC}(K_2, M)$

☐ (A) Bob can guarantee M is from Alice

☐ (B) Bob can guarantee that M has not been changed by Mallory

☐ (C) Mallory cannot read M

☐ (D) Bob can always recover the message M

☐ (E) None of the above

☐ (F) ——

Q3.2 $\mathsf{Enc}(K_1, M), \mathsf{MAC}(K_2, \mathsf{Enc}(K_1, M))$

☐ (G) Bob can guarantee M is from Alice

☐ (H) Bob can guarantee that M has not been changed by Mallory

☐ (I) Mallory cannot read M

☐ (J) Bob can always recover the message M

☐ (K) None of the above

☐ (L) ——

Q3.3 $\mathsf{Hash}(M), \mathsf{MAC}(K_1, M)$

☐ (A) Bob can guarantee M is from Alice

☐ (B) Bob can guarantee that M has not been changed by Mallory

☐ (C) Mallory cannot read M

☐ (D) Bob can always recover the message M

☐ (E) None of the above

☐ (F) ——

Q3.4 To simplify their schemes, Alice and Bob decide to set $K_1 = K_2$. (In other words, K_1 and K_2 are the same key.) Does this affect the security of their cryptographic schemes?

◯ (G) Yes, because they should always use a different key for every algorithm

◯ (H) Yes, because they should always use a different key for every message

◯ (I) No, because the encryption and MAC schemes are secure.

◯ (J) No, because the keys cannot be brute-forced.

◯ (K) ——

◯ (L) ——