1. (3pts) Name one significant difference between a threat and a vulnerability.
   answer: Attackers launch threats where defenders are responsible for vulnerabilities. Several others.

2. (3pts) Suppose a password policy requires a 9-character password that may not end with an integer. How does this impact the password keyspace given that the previous policy called for an unrestricted 8-character password?
   answer: The increase in password length increases the password entropy, but not by as much as adding another character since some are prohibited.

3. (3pts) What does a pluggable authentication module do?
   answer: A pluggable authentication module is a library that implements one or more of the PAM interfaces, such as executing password authentication for the authentication interface and logging for the session interface.

4. (3pts) Why must a symmetric key cryptographic algorithm generate a mapping that is one-to-one?
   answer: Each unique plaintext must be transformed into a unique ciphertext, otherwise we could not decrypt it properly (would decrypt to one of multiple plaintexts).

5. (3pts) What is an advantage of symmetric key cryptography over public key cryptography? What is a disadvantage?
   answer: Adv: Symmetric key algorithms are much faster (bits of encryption per second). Disadv: Getting shared keys distributed securely is much harder in the symmetric case.

6. (3pts) Do we typically apply HMAC to symmetric or asymmetric cryptographic statements to protect integrity and provide authenticity? Why?
   answer: Symmetric. If we are using public key crypto, we can generate a signature to guarantee integrity/authenticity without needing to distribute an additional symmetric key. We already have established a symmetric key in the symmetric case.

7. (3pts) An HMAC, $H(k + d)$, when sent with a value $d$ enables a remote party that knows $k$ to detect a modification of the value $d$. How does the one-way property of cryptographic hash functions ensure that this is true?
   answer: The one-way property prevents an attacker from determining the secret $k$ by reversing the hash computation, so only the communication partners with $k$ could have generated HMAC value.
8. \( (3\text{pts}) \) The SSH protocol does not require a trusted third party (e.g., Kerberos) or a certificate authority (e.g., PKI). What is the basis for trust in the public key of a SSH server?

\textit{answer}: SSH is a public key approach, rather than a secret key approach in Kerberos, so we need to only obtain the mapping between the public key and machine reliably. This can be done offline since the number of machines that one depends on is modest, but we typically accept such certs blindly (SSH tells us if the key changes though).

9. \( (3\text{pts}) \) What is the purpose of a public key infrastructure (PKI)?

\textit{answer}: Provide an infrastructure for securely retrieving a principal’s public key certificate (public key to identity binding).

10. \( (3\text{pts}) \) Why is DNSSEC a good candidate to use a tree-based PKI authentication system?

\textit{answer}: DNS is already uses a tree structure for its root servers and domain servers, so a tree-based PKI can leverage this existing structure of DNS.

11. \( (3\text{pts}) \) What parts of an IP packet are protected by the IPsec authentication header protections? Protected for confidentiality, integrity or both?

\textit{answer}: Integrity only. Packet data and IP header are protected, excepting mutable fields.

12. \( (3\text{pts}) \) A worm is launched. If it takes 1 minute for each infected system to find and infect another host, how many hosts would be infected after 10 minutes?

\textit{answer}: 1024

13. \( (3\text{pts}) \) What does the following protocol prove to Bob about the party claiming to be Alice? What does it prove to “Alice” about Bob?

\begin{align*}
A & \rightarrow B & \text{“I’m Alice”} \\
B & \rightarrow A & E(K_{AB}, R) \\
A & \rightarrow B & R
\end{align*}

\textit{answer}: Bob knows that the responding party (perhaps Alice, but maybe not) really knows the key \( K_{AB} \) after the third message (presuming Bob chose a good challenge). If Bob has only shared \( K_{AB} \) with Alice, and he trusts that Alice protects this key from theft, then he may assume that Alice is indeed the responding party. Alice learns nothing about whether Bob knows \( K_{AB} \) as message 2 could be a replay.

14. \( (3\text{pts}) \) We choose a RSA private key as a number that is relatively prime to \( \phi(n) \). How many values are relatively prime to \( \phi(n) \)? So what is the keyspace of a RSA private key? What is the entropy of a RSA private key?

\textit{answer}: \( \phi(n) \) tells us the number of integers that are relatively-prime to any \( n \). A private key will come from the set of integers that are relatively prime to \( \phi(n) \) which is \( \phi(\phi(n)) \). The number of possible private keys is the keyspace. The entropy \( \log_2(\phi(n)) \).
15. (7pts) What is the purpose of a Kerberos authenticator? Which part of the Needham-Schroeder protocol does it implement? How does it satisfy the requirements of those Needham-Schroeder messages?

Answer: An authenticator enables Bob to prove the freshness of Alice’s message by verifying the timestamp is within the current time window (and does not match a previous message). It replaces the 4th and 5th N-S messages. In these messages, Bob generates a nonce and requires that Alice demonstrate her current knowledge of the session key by generating a message that demonstrates her knowledge of the nonce. The timestamp enables this guarantee because only someone with knowledge of the session key could encrypt a current timestamp (if we verify that the message is not a replay).

16. (7pts) Why is Diffie-Hellman susceptible to man-in-the-middle attacks? Name one way to prevent such attacks.

Answer: Any party could generate a Diffie-Hellman key exchange message as there is no identifying secret in the protocol. With a public key infrastructure, principals could sign the key exchange messages.

17. (7pts) It is said that IPsec authentication header (AH) protocol is now subsumed by encapsulated security payload (ESP) protocol in tunnel mode. Specify how ESP in tunnel mode achieves the guarantees of AH.

Answer: ESP can provide authenticity using HMAC for the packet data (with or without encryption, using “null” encryption). In tunnel mode, the entire IP packet, including the IP header is encapsulated by ESP, so by providing authenticity protection for packet data, ESP in tunnel mode protects the header and packet data as the AH protocol does.

18. (7pts) Suppose there is a proposal for a new message digest algorithm that: (1) breaks a message into 160-bit chunks; (2) applies xor to all the chunks to get a 160-bit result; and (3) applies a traditional hash function (SHA-1) to the result. What hash property does this new digest algorithm break and why?

Answer: xor of different pairs may result in the same value (e.g., $1111 \oplus 1111 == 0000 \oplus 0000$), so this hash variant will not be collision-free.

Word Problems - take your time and answer clearly and completely.

19. (10pts) Perform the following RSA key generation steps. Each step must satisfy the requirements for a legitimate RSA key.

(a) (2pts) Suppose $n$ is 55. Find suitable $p$ and $q$ values.

(b) (2pts) Compute $\phi(n)$.

(c) (3pts) If $d = 7$, compute a valid value for $e$ and specify the public and private keys.
(d) (2pts) If Bob uses the same $n$ for his key pair, and his public key is 3, what is his private key?

(e) (1pt) Is it a good idea for multiple users to have public key pairs based on the same $n$?

answer: (a) $p = 5$ and $q = 11$.
(b) $\phi(n) = (p-1)(q-1) = 4 \times 10 = 40$.
(c) $d \equiv 7 \cdot e \mod 40; 7e \mod 40 = 1$ when $e = 23$. Private key is $\{7, 55\}$ and public key is $\{3, 55\}$.
(d) $d \equiv 3 \cdot e \mod 40; 3d \mod 40 = 1$ when $d = 17$. Private key is $\{17, 55\}$.
(e) No way.

20. (10pts) Design web cookie that stores the name of a user N and IP address of her computer IP that meets the specified requirements below. Your server has a symmetric key $K$ and a public key pair $K^+$ and $K^−$.

(a) (2pts) Using the symmetric key, design a cookie where the server can verify that it generated the cookie and its integrity is intact.

(b) (2pts) Using the symmetric key, design a cookie where the confidentiality of the information is protected and the server can verify that it generated the cookie and its integrity is intact.

(c) (2pts) Using public key cryptography, design a cookie where the server can verify that it generated the cookie and its integrity is intact.

(d) (2pts) Using public key cryptography, design a cookie where the confidentiality of the information is protected and the server can verify that it generated the cookie and its integrity is intact.
(e) (2pts) Using which approach, will it be faster to decrypt the cookie and verify its integrity?

**Answer:**

Suppose the cookie is $C = \{N, IP\}$.

(a) $C + HMAC(K, C)$
(b) $E(K, C) + HMAC(K, C)$
(c) Where $S(K^-, X)$ is signature, cookie is: $C + S(K^-, C)$
(d) $E(K^+, C) + S(K^-, C)$ (e) symmetric key

21. (10pts) Suppose you have a network as defined below. Create stateless firewall policies for the following network firewalls FW1 and FW2. Create only as as many rules as you need (use the minimum) in the order they should be evaluated.

(a) Unless otherwise specified, all traffic should be denied.
(b) The satellite networks, except those matching 129.168.*,.*, should be able to communicate with a DMZ web server host 128.168.11.2 over http (port 80).
(c) Satellite network 11.14.0.0 should be able to speak with any DMZ host over ssh (port 22).
(d) Nobody outside the DMZ should be able to contact the internal network.
(e) Any DMZ system should be able to talk to the DMZ SMTP server 128.168.11.5 (port 25).
(f) Any host in the internal network should be allowed to talk to the DMZ SMTP server (port 25).
(g) Any DMZ host should be allowed to talk to any internal network host via vsftp (port 21).
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**answer:**

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