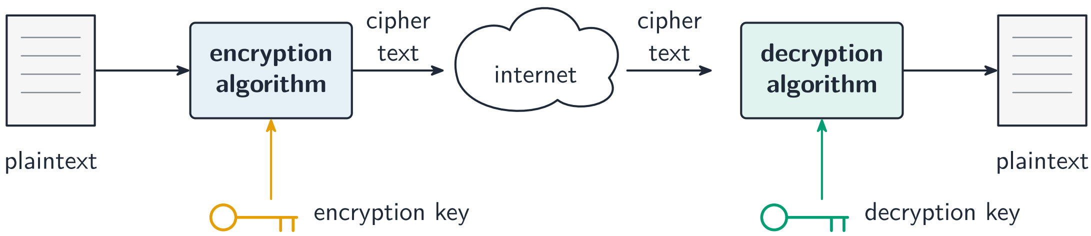
Security

A-Level Computer Science

How encryption works

Encryption 加密 turns readable **plaintext** 明文 (plain text) into unreadable **ciphertext** 密文 (cipher text) using a maths operation that depends on a **key**. Only someone with the right key can reverse it — **decryption** 解密 — to get the plaintext back. An attacker who intercepts the ciphertext without the key sees only meaningless data, because trying every possible key would take far too long. A newer approach, **quantum cryptography** 量子密码学, uses quantum physics to share a key in a way that reveals any eavesdropper.

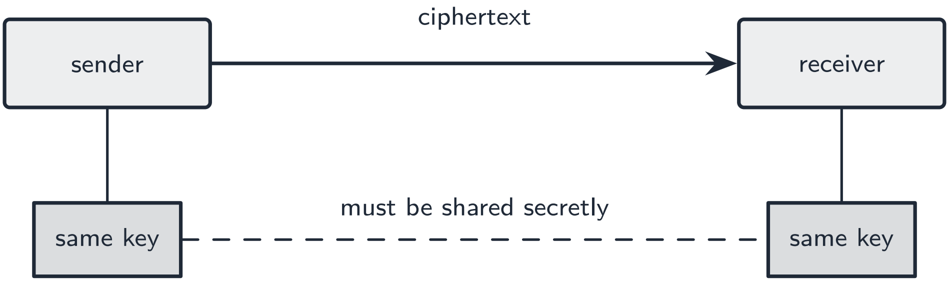
The Enigma machine encrypted messages in the Second World War — an early, mechanical cipher device



Encryption scrambles plaintext with a key; decryption reverses it

Symmetric encryption

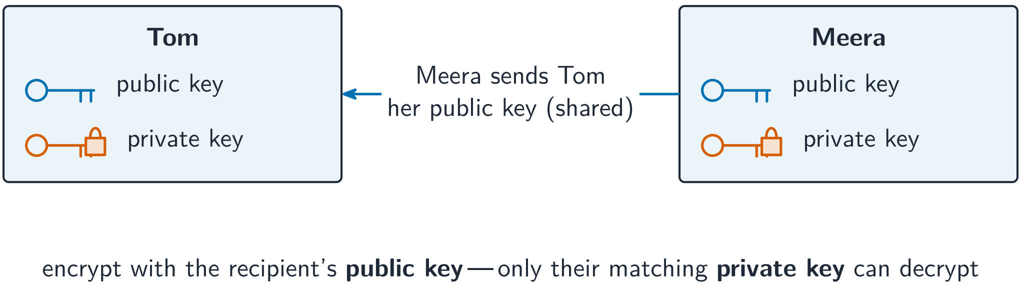
Symmetric encryption 对称加密 (symmetric key cryptography) uses the **same key** for both encryption and decryption, so sender and receiver must both hold the secret key. It is **fast** and good for **bulk data** (a whole disk, a video stream). Its problem is **key distribution** 密钥分发: how do you share the key safely in the first place? Asymmetric encryption solves this.



Symmetric encryption uses the same secret key at both ends

Asymmetric encryption (public-key)

Asymmetric encryption 非对称加密 (asymmetric key cryptography) gives each user a **pair** of related keys: a **public key** 公钥 they publish, and a **private key** 私钥 they keep secret. Data encrypted with the public key can be decrypted **only** with the matching private key, and vice versa.



Each user has a public key to share and a private key to keep secret

To send a secret message to Alice: get her published public key, encrypt with it, and send. Only Alice — holding the matching private key — can decrypt. No prior key exchange is needed. The trade-off is that it is **much slower** than symmetric, so it is not used for large data.

A private key must stay secret, so it is sometimes kept on a small **hardware security key** 硬件安全密钥. You plug it in or tap it to prove who you are, and the secret key never leaves the device.

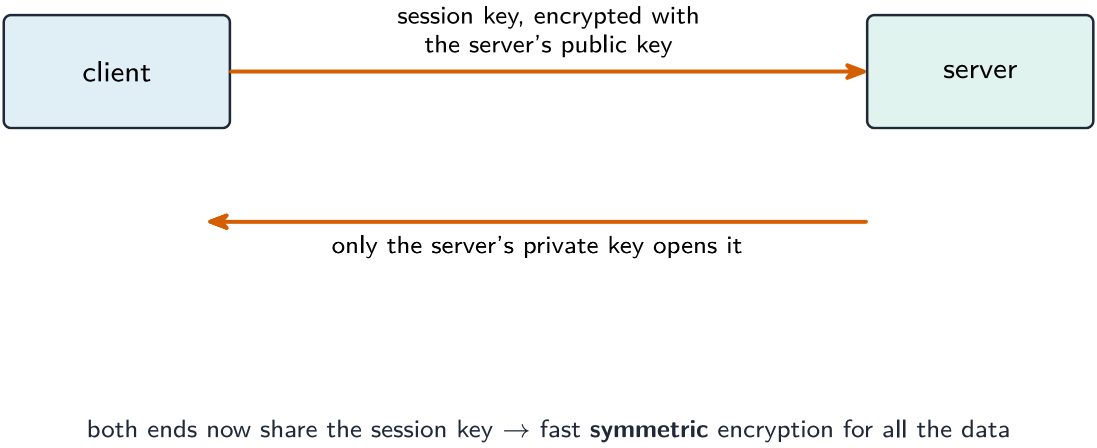
A hardware security key stores a secret key to prove who you are

Hybrid approach (used by almost every real system)

Use asymmetric encryption to exchange a fresh **session key** 会话密钥, then use that symmetric key for the data:

1. the client makes a random session key.
2. it encrypts the session key with the server's public key.
3. the server decrypts it with its private key.
4. both ends now share the session key and use fast symmetric encryption for the rest.

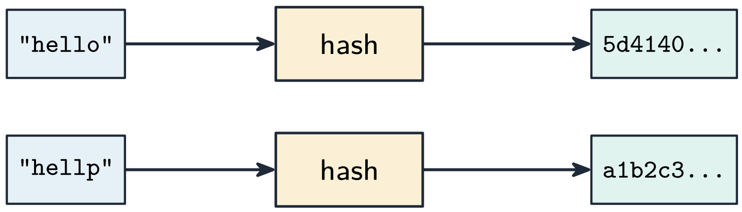
This is how HTTPS and SSH work.



The hybrid approach: asymmetric crypto shares a session key once, then fast symmetric encryption protects the data

Hashing (related, not encryption)

A **cryptographic hash** 密码散列 function takes any input and gives a fixed-size **digest** 摘要 such that the same input always gives the same digest, it is infeasible to find two inputs with the same digest, and a tiny change in input changes the digest completely. Hashing is **one-way** — you cannot get the input back. It is used for storing password checks, **integrity** 完整性 checks, and digital signatures.



one letter changed → a completely different digest; one-way (cannot reverse)

A cryptographic hash gives a fixed digest; a tiny input change changes it completely, and it cannot be reversed

SSL / TLS

TLS 传输层安全 (Transport Layer Security, the successor to the **Secure Socket Layer**, SSL) is a **protocol** that gives encryption and authentication for data sent over a network. It **encrypts** the data in transit, **authenticates** the server with a certificate, and provides **integrity** (detecting tampering).

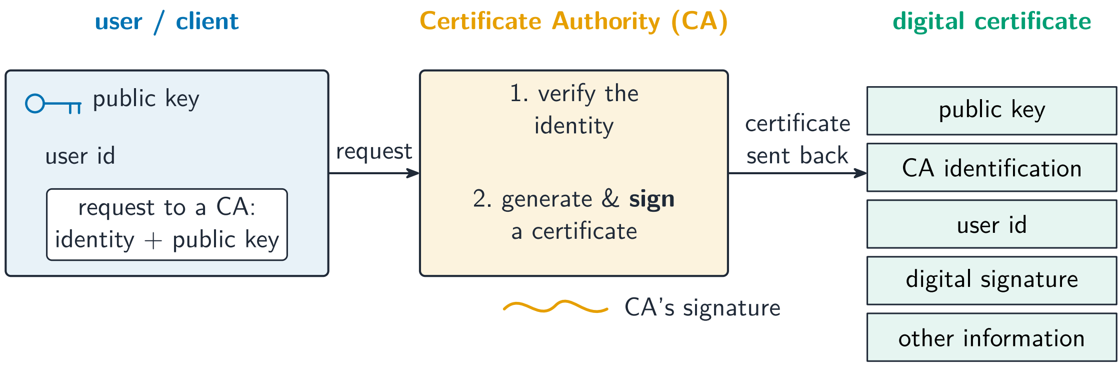
Outline of a TLS handshake:

1. the client connects and proposes cipher options.
2. the server picks one and sends its **digital certificate** (with its public key) — issuing and validating these certificates is **digital certification**.
3. the client checks the certificate.
4. the two ends exchange a fresh **session key** using asymmetric crypto.
5. all later traffic uses fast symmetric encryption with the session key.

The result is an encrypted, authenticated, integrity-checked tunnel for higher-level protocols (HTTP, SMTP). It is appropriate wherever **sensitive information** is sent: HTTPS web browsing, online banking and payments, secure email, and VPNs.

Digital certificates

A **digital certificate** 数字证书 binds an identity (a domain, an organisation) to a public key, and is signed by a trusted **Certificate Authority** 证书颁发机构 (CA). It contains the subject (who it identifies), the subject's public key, the issuer (the CA), a validity period, and the CA's signature over all of it.



A Certificate Authority issues a digital certificate binding an identity to a public key

To verify one, the client (which holds a list of trusted root CAs):

1. checks the expiry dates.
2. checks the subject name matches the URL.
3. checks it is **signed by a trusted CA**, using the CA's public key to verify the signature.
4. follows the certificate chain up to a trusted root.

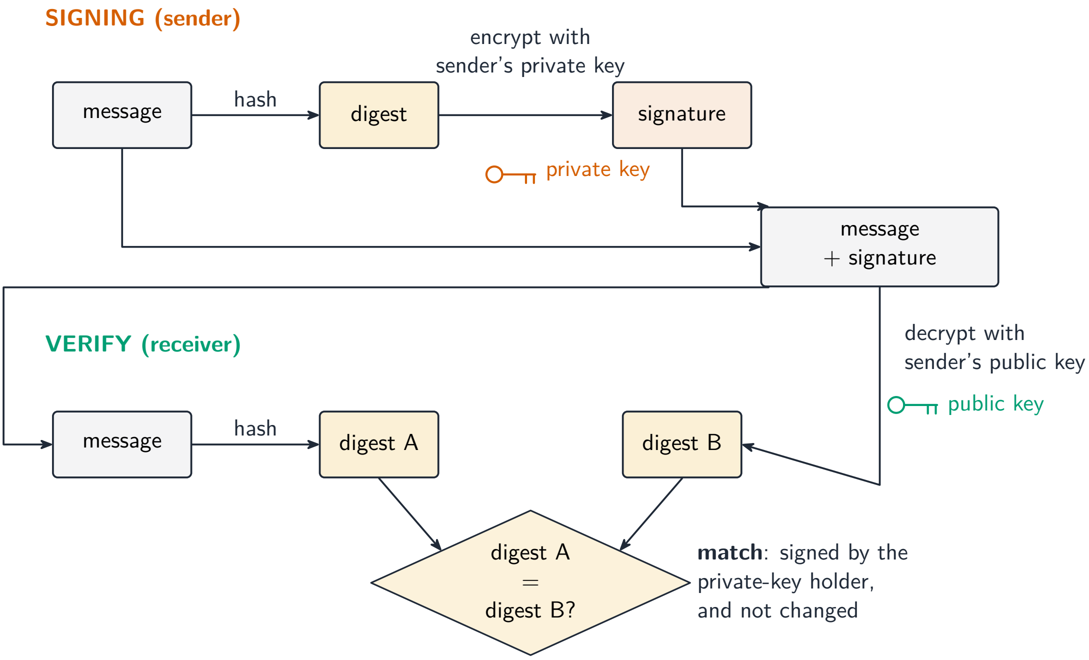
If anything fails, the browser shows the "Your connection is not private" warning. When it verifies cleanly, the client knows the identity was vetted by a trusted CA, the public key really belongs to that identity, and the certificate is current.

Digital signatures

A **digital signature** 数字签名 proves who signed a message **and** that it was not changed. To sign:

1. compute a cryptographic hash of the message.
2. **encrypt the hash with the sender's private key** — that is the signature.
3. send the message and the signature.

To verify: compute the hash of the received message; **decrypt the signature with the sender's public key** to get the sender's hash; compare. If they match, the message was signed by the holder of the private key (**authentication 身份验证**) and was not changed (integrity). A signature does **not** hide the message — for confidentiality as well, encrypt **and** sign.



Signing hashes the message and encrypts the digest with the private key; the receiver checks it with the public key

Putting it together

A secure request to `https://www.bank.com`: the server sends its certificate; the client verifies it against trusted CAs; the client uses the server's public key to exchange a session key; then data flows encrypted with that key. Encryption stops eavesdroppers, the certificate proves the server's identity, and integrity checks stop a **man-in-the-middle 中间人攻击** altering the data.

Worked example. Alice sends Bob a contract. She wants Bob to be certain it came from her and was not altered, **and** she wants nobody else to be able to read it. Which keys does she use, and in which direction? These are two different jobs needing two different key pairs. For the **signature** (authentication and integrity): Alice hashes the contract and encrypts that hash with **her own private key**; Bob decrypts it with **Alice's public key** and compares it against his own hash of the message. Only Alice holds her private key, so only she could have produced it. For **confidentiality**: Alice encrypts the contract itself with **Bob's public key**, so only **Bob's private key** can open it. One rule keeps all four straight: you **sign with your own private key** and **encrypt with the recipient's public key**. A signature on its own does **not** hide the message.

Exam tips

- Distinguish **symmetric** encryption (one shared key, fast) from **asymmetric** (a public/private key pair).
- Explain the **TLS handshake** and why a **digital certificate** from a CA proves identity.
- Explain a **digital signature**: hash the message, then encrypt the hash with the private key — it proves integrity and origin.