how does an electret microphone work

An **electret microphone** is a type of **condenser (capacitor) microphone** that has a *permanently charged material* inside — which lets it work without needing an external high-voltage power supply.

Here's the idea step-by-step.

🎤 1. The basic principle: sound → electrical signal

An electret mic converts **sound waves** into electricity using **capacitance changes**.

Inside the microphone are two main parts:

- a **thin movable diaphragm**
- a **fixed back plate**

Together, they form a tiny capacitor.

When sound waves hit the diaphragm:

- air pressure makes it vibrate
- the distance between diaphragm and back plate changes
- the capacitor's electrical properties change

This variation creates an electrical signal that matches the sound.

⚡ 2. What makes it an *electret* microphone?

In a normal condenser microphone, the capacitor plates must be charged using an external voltage (like phantom power).

An electret microphone instead uses an **electret material**.

An **electret** is:

- a dielectric material

- that holds a **permanent electric charge**
- similar to how a magnet permanently holds a magnetic field

Because the charge is already built in:
✅ no external polarization voltage is needed
✅ the microphone can be very small and cheap

🔋 3. Why it still needs power

Even though the electret provides the charge, the microphone usually still needs **low-voltage power** (typically 1.5–5 V).

That power runs a tiny internal amplifier:

👉 usually a **JFET transistor**

Why this is needed:

- the capacitor signal has **very high impedance**
- cables and circuits cannot handle it directly
- the JFET converts it into a usable low-impedance output

So power is for amplification — **not** for creating the charge.

🧩 4. Internal structure (simplified)

Code

```
Sound waves
     ↓
[ Diaphragm ]  ← moves
     ||
[ Electret layer ]
     ||
[ Back plate ]
     ↓
Capacitance change
     ↓
JFET buffer amplifier
     ↓
Audio signal output
```

✅ 5. Why electret microphones are everywhere

They are used in:

- smartphones
- laptops
- headsets
- hearing aids
- lavalier microphones
- webcams

because they are:

- tiny
- inexpensive
- sensitive
- low power

🧠 Quick analogy

Think of it like:

- **sound pushes a charged membrane**
- movement changes an electric field
- electronics translate that movement into voltage

If you want, I can also explain:

- the difference between **electret vs dynamic microphones**
- how MEMS microphones evolved from electrets
- or show the exact circuit used with Arduino/Raspberry Pi.

can you explain physical details and metric for small elecetret microphone

Sure — let's go deeper into the **physical construction**, **dimensions**, and **typical electrical/mechanical metrics** of a *small electret microphone capsule* (the kind used in phones, headsets, Arduino projects, etc.).

🎤 1. Physical construction (real internal layers)

A small electret microphone capsule is basically a **precision electro-mechanical system** packed into a metal can.

Main internal parts

From front → back:

‹/› Code

```
Sound hole
   ↓
Metal case (ground)
   ↓
Flexible diaphragm (metalized polymer)
   ↓   ← air gap (~10–30 µm)
Electret layer (charged dielectric)
   ↓
Backplate (metal electrode)
   ↓
JFET preamplifier chip
   ↓
Output pin + ground case
```

🧩 Diaphragm

- Material: **Mylar (PET)** or similar polymer
- Coating: ultra-thin metal layer (gold/aluminum)
- Thickness:
  2–6 µm
- Diameter:
  4–10 mm (depending on capsule size)

The diaphragm must be:

- extremely light
- mechanically elastic
- electrically conductive

⚡ Electret layer

This is the key component.

Typical materials:

- PTFE (Teflon)
- fluoropolymer films

Properties:

- permanently trapped electric charge

- surface charge density ≈ **0.5–2 mC/m^2**

Charge lifetime:
✅ often **20–50 years**

📏 Air gap (critical dimension)

Distance between diaphragm and backplate:

👉 **10–30 micrometers**

This tiny spacing determines:

- sensitivity
- noise
- frequency response

Too large → low sensitivity
Too small → diaphragm sticks

📦 2. Typical capsule sizes

Common commercial electret microphone diameters:

Type	Diameter	Height
Mini	4 mm	1.5–2 mm
Standard	6 mm	2.2–3 mm
Large	9–10 mm	4–6 mm

Example:

- Very common capsule: **6 × 2.7 mm**

Weight:
≈ **0.1–0.3 g**

🔌 3. Electrical characteristics (typical)

Internal capacitance

The diaphragm + backplate form a capacitor:

$$C = 10\text{–}50\ pF$$

Very small — which is why amplification is required immediately.

Bias / supply voltage

Needed for internal JFET:

- **1.5 – 10 V**
- typical: **2 V**

Current consumption:

- **0.2 – 0.8 mA**

Output impedance

After JFET buffer:

- **1–3 kΩ**

Without the JFET:
👉 hundreds of megaohms.

🔊 4. Acoustic performance metrics

Sensitivity

Measured at **1 kHz, 94 dB SPL**

Typical:

$$-44\ \mathrm{dBV/Pa}$$

(range −35 to −50 dBV/Pa)

Meaning:
94 dB sound pressure produces about:

$$\approx 6\text{–}10 \text{ mV RMS}$$

Frequency response

Typical small capsule:

- **20 Hz – 16 kHz**
- speech-optimized versions:
  100 Hz – 10 kHz

High-frequency limit mainly depends on diaphragm mass.

Signal-to-noise ratio (SNR)

Usually:

- **55–70 dB**

Equivalent noise level:

- **24–35 dBA**

Maximum sound pressure level

Before distortion:

- **110–130 dB SPL**

🧠 5. Mechanical physics (why it works well)

The diaphragm behaves like a **tensioned circular membrane**.

Key physical relationships:

Resonant frequency

Approximately:

$$f_0 \propto \sqrt{\frac{T}{\rho}}$$

where:

- T = diaphragm tension
- ρ = surface mass density

Designers tune tension so resonance lies **above speech range**.

Capacitance variation

Sound causes displacement:

$$C = \frac{\varepsilon A}{d}$$

Small motion (~nanometers!) changes distance d,
producing measurable voltage variation.

Typical diaphragm motion:

- **10–100 nm** for normal speech.

That's smaller than bacteria.

🔬 6. Why the metal case matters

The outer can is not just protection:

✅ electromagnetic shielding
✅ acoustic cavity tuning
✅ ground reference
✅ mechanical stiffness

The front hole size controls high-frequency response.

⚙️ 7. Real example specification (6 mm capsule)

Parameter	Value
Diameter	6 mm
Height	2.7 mm
Capacitance	20 pF

Parameter	Value
Supply	2 V
Current	0.5 mA
Sensitivity	−44 dBV/Pa
SNR	60 dB
Max SPL	120 dB

If you want next, I can show you **the full small-signal equivalent circuit** (with equations) or explain **how manufacturers tune frequency response mechanically** — which is surprisingly clever engineering.

show the full small-signal equivalent circuit

Good — now we move to the **engineering model** used when designing real microphone preamps.

The **small-signal equivalent circuit** of an electret microphone combines:

1. **variable capacitor transducer**
2. **built-in JFET impedance converter**
3. **bias network**

🎤 Small-Signal Equivalent Circuit of an Electret Microphone

Below is the practical electrical model used in circuit analysis.

Code

```
          Sound pressure
                ↓
     ┌─────────────────────┐
     │  Acoustic domain    │
     └─────────────────────┘

            ↓ converted to

     Variable capacitor model

            ΔC(t)
              │
              │
       ┌──────┴───────┐
       │               │
     C0 + ΔC         Rleak
       │               │
       └──────┬────────┘
              │
           Gate (G)
            JFET
              │
       ┌──────┴───────┐
       │               │
      gm·vgs         ro
       │               │
       └──────┬────────┘
              │
            Drain
              │
           Output
              │
           RD (bias)
              │
             Vbias
```

Let's break this carefully.

1️⃣ Capacitor Transducer Model

The microphone capsule behaves as a **charged capacitor**.

Static capacitance

$$C_0 \approx 10\text{–}50\,pF$$

Sound causes displacement:

$$C(t) = C_0 + \Delta C(t)$$

Because charge already exists (electret),

$$Q = \text{constant}$$

so voltage varies:

$$V = \frac{Q}{C}$$

Small change gives:

$$v_{sig} \approx -\frac{Q}{C_0^2} \Delta C$$

✅ Mechanical motion → voltage signal.

Leakage resistance

Real capsules include:

$$R_{leak} = 1\text{–}10\, G\Omega$$

representing:

- dielectric leakage
- humidity paths

This sets **very low-frequency rolloff**.

2️⃣ Why a JFET is Required

The raw capsule impedance:

$$Z_C = \frac{1}{\omega C}$$

Example at 1 kHz:

$$C = 20pF$$

$$Z_C \approx 8\, M\Omega$$

Impossible to drive cables directly.

So manufacturers place a **JFET source follower** inside.

3️⃣ JFET Small-Signal Model

Inside nearly every electret mic:

👉 **common-drain (source follower)**

Equivalent model

Parameters:

- transconductance:

$$g_m \approx 0.3\text{–}1\,mS$$

- output resistance:

$$r_o \approx 20\text{–}100k\Omega$$

Small-signal drain current:

$$i_d = g_m v_{gs}$$

4️⃣ External Bias Resistor

Typical real connection:

```
Vbias (2–5V)
      |
     RB
      |------ audio output
      |
   Electret Mic
      |
     GND
```

Where:

$$R_B = 2.2k\Omega \text{ to } 10k\Omega$$

This resistor:

✅ powers JFET

✅ converts current variations → voltage signal

Output voltage:

$$v_o = -i_d R_B$$

5️⃣ Complete Linear Small-Signal Model

Putting everything together:

Code

```
Acoustic pressure
       ↓
Mechanical displacement
       ↓
ΔC(t)
       ↓
Voltage source vsig
       │
       ├── C0
       ├── Rleak
       │
      Gate
       │
    JFET gm·vgs
       │
      Source
       │
      GND

Drain → RB → Vbias
          │
        Output
```

6️⃣ Frequency Response Mechanisms

Three dominant poles appear:

(A) Low-frequency cutoff

From leakage:

$$f_L = \frac{1}{2\pi R_{leak} C_0}$$

Typically:

- **5–50 Hz**

(B) Output high-pass (coupling capacitor)

If output capacitor exists:

$$f = \frac{1}{2\pi R_{load} C_{out}}$$

(C) High-frequency rolloff

Caused by:

- diaphragm mass
- acoustic damping
- FET capacitances

Usually:

10–20 kHz

7️⃣ Key Insight (Important)

An electret microphone is electrically equivalent to:

✅ a **charge-biased variable capacitor voltage source**

followed by

✅ a **JFET source follower buffer**

So internally it behaves almost like:

> **a tiny built-in preamplified condenser microphone**

8️⃣ Typical Small-Signal Numbers

Parameter	Typical
Capsule capacitance	20 pF
Gate impedance	>1 GΩ
gm	0.5 mS
Output impedance	1–3 kΩ
Output signal	5–20 mV RMS
Bias voltage	2 V

If you want, next I can show something very useful:

✅ **SPICE equivalent model**
✅ **noise model (why electrets hiss)**
✅ **derivation from acoustic pressure → volts**
✅ **why MEMS microphones replaced electrets in phones**

Just tell me which direction you want.