SI PREFIXES & UNITS

T / G / M / k	10^{12} / 10^{9} / 10^{6} / 10^{3}
m / μ / n / p	10^{-3} / 10^{-6} / 10^{-9} / 10^{-12}
A	C/s · V = J/C
W	J/s = V·A
S (siemens)	Ω^{-1}, conductance $G = 1/R$
kW·h	3.6×10^{6} J

CHARGE · CURRENT · VOLTAGE

Current	$i(t) = \frac{dq}{dt}$
Charge	$q(t_1) = \int_{t_0}^{t_1} i\,dt + q(t_0)$
Constant i	$q = i\,\Delta t$
Double subscript	$v_{ab} = v_a - v_b,\ v_{ba} = -v_{ab}$
Reference	Polarity/direction is a *choice*. Negative answer ⇒ true direction is opposite. Never re-draw, just report the sign.

POWER & PASSIVE SIGN CONVENTION

Power	$p = v\,i$ (W)
Energy	$w = \int_{t_0}^{t_1} p\,dt$ (J)
PSC	Current **enters +** terminal ⇒ $p = vi$ is power **absorbed**
Active config	Current **exits +** terminal ⇒ $p = -vi$; element **supplies**
Balance	$\sum p = 0$ over the whole circuit (supplied = absorbed) — always use as a check

OHM'S LAW & RESISTORS

Ohm	$v = iR,\ i = Gv,\ G = 1/R$
Dissipation	$p = vi = i^2R = \frac{v^2}{R} \geq 0$ always
Geometry	$R = \frac{\rho L}{A},\ \rho_{\text{copper}} = 1.72 \times 10^{-8}\ \Omega\text{m}$
Ideal wire	$R = 0$ ⇒ zero drop; both ends are the **same node**
Open circuit	$i = 0$ (any v) · Short: $v = 0$ (any i)

KCL & KVL

KCL	$\sum i_{\text{in}} = \sum i_{\text{out}}$ at any node (charge conservation)
KVL	$\sum v = 0$ around any closed loop (energy conservation)
KVL rule	Traverse the loop; use the **first polarity sign encountered** (+ ⇒ add, − ⇒ subtract)
Series	same current through every element
Parallel	same voltage across every element

SERIES / PARALLEL — ALL ELEMENTS

R series	$R_{eq} = \sum R_k$
R parallel	$\frac{1}{R_{eq}} = \sum \frac{1}{R_k}$; two: $\frac{R_1R_2}{R_1 + R_2}$
L	series $L_{eq} = \sum L_k$; parallel $\frac{1}{L_{eq}} = \sum \frac{1}{L_k}$ (*like R*)
C	series $\frac{1}{C_{eq}} = \sum \frac{1}{C_k}$; parallel $C_{eq} = \sum C_k$ (*opposite of R*)
Z	series $Z_{eq} = \sum Z_k$; parallel $\frac{1}{Z_{eq}} = \sum \frac{1}{Z_k}$

DIVIDERS

Voltage divider	$V_n = \frac{R_n}{R_1 + \cdots + R_N} V_{\text{total}}$ (series only)
Current divider	$i_1 = \frac{R_2}{R_1 + R_2} i_{\text{total}}$ (2 branches, parallel only)
General CD	$i_k = \frac{G_k}{\sum G} i_{\text{total}} = \frac{R_{eq}}{R_k} i_{\text{total}}$
Watch	VD: bigger R gets more v. CD: bigger R gets **less** i — the opposite resistor is on top.
AC form	Same formulas with Z in place of R.

NODE-VOLTAGE ANALYSIS

1	Pick reference (ground) — usually the − terminal of the largest source / most-connected node.
2	Label $v_1, v_2, \ldots$ at remaining nodes.
3	KCL at each unknown node with **ALL CURRENTS LEAVING** — the course convention, keep it every time.
Branch term	$\frac{v_{\text{this}} - v_{\text{other}}}{R}$ (this node's v first)
To ground	$\frac{v_{\text{this}}}{R}$
Source at node	If v_s ties a node to ground: $v_1 = v_s$, write **no** KCL there.

SUPERNODES & DEPENDENT SOURCES

When	A voltage source sits between two *non-reference* nodes (its current is unknown).
Do	Draw a bubble around both nodes + the source; write one KCL for everything **leaving the bubble**.
Plus constraint	KVL across the source: $v_{(+\text{ node})} - v_{(-\text{ node})} = V_s$
Dependent src	Treat as an ordinary source, then add the **control equation** expressing v_x or i_x in node voltages.
Never	Never deactivate a dependent source (superposition, R_{Th} — see those cards).

MESH-CURRENT ANALYSIS

1	Assign a mesh current to every window pane, **all clockwise** (course convention).
2	KVL around each mesh in the direction of its own current.
Own resistor	drop $= i_kR$
Shared resistor	drop $= (i_k - i_{\text{adj}})R$ — **own current first**
Current src in one mesh	$i_k = \pm I_s$ directly; skip that KVL.
Src between meshes	**Supermesh**: KVL around the outside of both, plus $i_k - i_j = I_s$.

THÉVENIN & NORTON

Thévenin	V_{Th} in **series** with R_{Th}
Norton	I_N in **parallel** with R_N
V_{Th}	$= v_{oc}$ with the load **removed**
I_N	$= i_{sc}$ with the terminals **shorted**
R_{Th}	$= R_N = \frac{v_{oc}}{i_{sc}}$
Source-kill R_{Th}	Only if **no dependent sources**: V-src → short, I-src → open, then reduce series/parallel.

SUPERPOSITION

Procedure	Leave one independent source on, deactivate the rest, solve; repeat; add all contributions *with sign*.
Deactivate	voltage source → **short** (0 V) · current source → **open** (0 A)
Dependent	ALWAYS left active in every sub-circuit.
NOT for power	$p \propto i^2$ is nonlinear — sum i first, *then* compute p.

WHEATSTONE BRIDGE

Layout	R_1, R_2 one leg; R_3, R_4 other leg; meter across the two midpoints.
Balanced	$\frac{R_1}{R_2} = \frac{R_3}{R_4} \iff R_1R_4 = R_2R_3$
At balance	$v_{\text{bridge}} = 0$, no current through the meter branch — it can be removed *or* shorted freely.
Unknown	$R_x = R_{\text{known}} \frac{R_2}{R_1}$

CAPACITORS

i–v	$i = C\frac{dv}{dt}$
v from i	$v(t) = \frac{1}{C}\int_0^t i\,d\tau + v(0)$
Energy	$w = \frac{1}{2}Cv^2$ (stored, never dissipated)
Continuity	v_C **cannot jump**: $v_C(0^+) = v_C(0^-)$ (a jump needs infinite i); i_C can jump freely.
DC steady state	**open circuit** ($dv/dt = 0 \Rightarrow i = 0$)

INDUCTORS

v–i	$v = L\frac{di}{dt}$ (H)
i from v	$i(t) = \frac{1}{L}\int_0^t v\,d\tau + i(0)$
Energy	$w = \frac{1}{2}Li^2$
Continuity	i_L **cannot jump**: $i_L(0^+) = i_L(0^-)$ (a jump needs infinite v)
DC steady state	**short circuit** ($di/dt = 0 \Rightarrow v = 0$)

FIRST-ORDER TRANSIENTS

Universal	$x(t) = x(\infty) + \left[x(0^+) - x(\infty)\right]e^{-t/\tau}$
τ	RC: $\tau = R_{Th}C$ · RL: $\tau = L/R_{Th}$
R_{Th}	resistance seen **by the C or L** with sources deactivated, *after* the switch moves
Charge/discharge	Charging: $v_C = V_s(1 - e^{-t/\tau})$. Discharging: $v_C = V_0 e^{-t/\tau}$. Charging current: $i = \frac{V_s}{R}e^{-t/\tau}$.

TRANSIENT PROCEDURE & T TABLE

1	$t < 0$: old circuit at DC steady state (C open, L short) ⇒ find $v_C(0^-)$ / $i_L(0^-)$.
2	Continuity: $v_C(0^+) = v_C(0^-)$, $i_L(0^+) = i_L(0^-)$.
3	$t \to \infty$: new circuit at DC steady state ⇒ $x(\infty)$.
4	τ from the **new** circuit's R_{Th}; substitute into the universal formula. Other quantities: get from v_C/i_L via Ohm/KVL, not another exponential.
Solve for t	$t = -\tau \ln \dfrac{x(t) - x(\infty)}{x(0^+) - x(\infty)}$

AC SINUSOIDS & RMS

Course form	$v(t) = V_m \sin(\omega t + \theta)$
ω	$= 2\pi f = \dfrac{2\pi}{T}$ (rad/s)
RMS	$V_{rms} = \dfrac{V_m}{\sqrt{2}} = 0.707\, V_m$ (sinusoids only)
Phase lead/lag	$\phi = \theta_v - \theta_i$. $\phi > 0$: v leads i (inductive). $\phi < 0$: i leads v (capacitive). $\Delta\phi = \omega\Delta t$.

PHASORS

Phasor	$\mathbf{V} = V\angle\theta$ — magnitude + phase at a fixed ω; time is dropped.
MUST DO FIRST	Put every source in **one** reference form (all sine or all cosine) before reading off angles.
Identity	$\sin(\omega t + \theta) = \cos(\omega t + \theta - 90^\circ)$; $-\sin(x) = \sin(x \pm 180^\circ)$ — a minus sign is a 180° shift.
Magnitude	State whether you're using peak or RMS phasors and **stay consistent**; AC power formulas below assume RMS.

COMPLEX ARITHMETIC

Engineering	$j = \sqrt{-1}$ (never i — that's current)
Rect → polar	$\lvert Z\rvert = \sqrt{R^2 + X^2}$, $\angle Z = \arctan \dfrac{X}{R}$ (if $R < 0$, add 180° — calculators only return $\pm 90^\circ$)
Polar → rect	$Z = \lvert Z\rvert \cos\theta + j\lvert Z\rvert \sin\theta$
+/− vs ×/÷	**+/−** use **rectangular**. ×/÷ use **polar**: multiply/divide magnitudes, add/subtract angles.
j powers	$j^2 = -1$, $\dfrac{1}{j} = -j$, $j = 1\angle 90^\circ$

COMPLEX IMPEDANCE

Phasor Ohm	$\mathbf{V} = \mathbf{ZI}$
Resistor	$Z_R = R = R\angle 0^\circ$ — v, i in phase
Inductor	$Z_L = j\omega L = \omega L\angle 90^\circ$ — v **leads** i by 90°
Capacitor	$Z_C = \dfrac{-j}{\omega C} = \dfrac{1}{\omega C}\angle -90^\circ$ — i **leads** v by 90°
Reactance	$X_L = \omega L$, $X_C = -\dfrac{1}{\omega C}$; $Z = R + jX$; $Y = 1/Z = G + jB$ (S). $\omega \to 0$: $Z_L \to 0$, $\lvert Z_C\rvert \to \infty$ (matches DC). $\omega \to \infty$: reverse.

AC CIRCUIT ANALYSIS

1	Fix ω; convert every source to a phasor and every R/L/C to an impedance.
2	Every DC technique applies unchanged with Z for R : series/parallel, dividers, node, mesh, Thévenin, superposition.
3	Do the complex algebra (polar for ×/÷, rectangular for +/−).
Z_{Th}	same rules as R_{Th}, complex-valued. Series RLC: $Z = R + j(\omega L - \frac{1}{\omega C})$.
Resonance	$\omega_0 = \dfrac{1}{\sqrt{LC}}$: X cancels, $Z = R$ (purely real, PF$= 1$). $\lvert\mathbf{V}_L\rvert, \lvert\mathbf{V}_C\rvert$ can each exceed the source — normal, not an error.

AC POWER (RMS VALUES)

Real	$P = V_{rms}I_{rms}\cos\phi$ (W) — only R dissipates
Reactive	$Q = V_{rms}I_{rms}\sin\phi$ (VAR) — stored/returned by L and C
Apparent	$S = V_{rms}I_{rms} = \sqrt{P^2 + Q^2}$ (VA)
⚠ Peak vs RMS	These need RMS. With peak phasors, $P = \frac{1}{2}V_m I_m \cos\phi$.
Power factor	$\mathrm{PF} = \cos\phi = \dfrac{P}{S}$, $0 \le \mathrm{PF} \le 1$. Lagging = inductive (i lags v); leading = capacitive (i leads v).

COMPLEX POWER & TRIANGLE

Complex power	$\mathbf{S} = \mathbf{V}_{rms}\mathbf{I}^*_{rms} = P + jQ = S\angle\phi$
Note	The conjugate on $\mathbf{I}$ is what makes $\angle\mathbf{S} = \theta_v - \theta_i$. Forgetting it flips the sign of Q.
Conservation	P and Q each add over all elements: $\sum P = 0$, $\sum Q = 0$. S does **not** add arithmetically.
⚠ Q sign	With $\phi = \theta_v - \theta_i$ and $\mathbf{S} = \mathbf{V}_{rms}\mathbf{I}^*_{rms}$: $Q > 0$ for an **inductive** (lagging) load, $Q < 0$ for capacitive (leading) — matches the course's own worked example ($\mathbf{V} = 120\angle 30^\circ$, $\mathbf{I} = 10\angle 0^\circ$, lagging, $Q = +600$ VAR). One slide bullet states the opposite rule in words; trust this formula and the worked numbers over that bullet.
PF correction	Add C in parallel to cancel inductive Q; P unchanged, S drops, $\mathrm{PF} \to 1$.

IDEAL OP-AMP

R_{in}	∞ ⇒ **no current into either input**
R_{out}	0 ⇒ ideal voltage source at the output
Golden rules	With **negative feedback**: $v_+ = v_-$ (virtual short) and $i_+ = i_- = 0$.
Virtual ground	If $+$ is tied to ground, then $v_- = 0$ V — but it is *not* a real ground; no current sinks into it.
Saturation	Output clips at the supply rails $\pm V_{CC}$; the golden rules stop holding there.

INVERTING AMPLIFIER

Circuit	$+$ to ground; v_{in} through R_{in} to the $-$ node; R_f from output back to $-$.
Gain	$A_v = \dfrac{v_{out}}{v_{in}} = -\dfrac{R_f}{R_{in}}$
Minus sign	180° inversion — positive in, negative out. Do not drop it.
Example	$R_f = 10$ kΩ, $R_{in} = 1$ kΩ ⇒ $A_v = -10$; 1 V in gives -10 V out. Always verify $\lvert v_{out}\rvert \le V_{CC}$, else it saturates.

EXAM GOTCHAS — FINAL CHECK

Signs	PSC: current into $+$ ⇒ absorbing. Node KCL: all currents leaving. Mesh: all clockwise. Deactivating: V-src→short, I-src→open, dependent sources never.
Units & mode	Convert kΩ/μF/mH *before* substituting (kΩ×mA=V; kΩ×μF=ms). Check degrees-vs-radians before every phasor problem.
Continuity & RMS	v_C, i_L continuous at $t = 0$, everything else can jump. Power formulas want RMS, not peak. Superposition never for power directly.
Verify	KCL at one node + KVL around one loop + $\sum p = 0$ catches most arithmetic slips.