

RUN THE NUMBERS

VOLUME 1

The Five NEC Calculations Every Exam

Asks — Worked Step by Step

**AMPACITY • CONDUIT FILL • BOX FILL
VOLTAGE DROP • MOTORS & TRANSFORMERS**

*A free companion to Michael Hamilton's Illustrated Guide
to Understanding the National Electrical Code, Vol. 1*

OAKWOOD PRESS

A Note Before You Start

Here's the thing nobody tells you about electrical licensing exams.

The Code-recall questions are the easy half. You either know that receptacles go every twelve feet or you don't, and you can fix "don't" with flashcards.

The calculations are where people actually fail. Not because the math is hard — it's arithmetic, and you've got a calculator. People fail because under time pressure they grab the wrong table, apply factors in the wrong order, or round the wrong direction. The answer they get is a *plausible* answer. It's on the multiple-choice list. It's just not the right one.

Calculation questions are designed that way on purpose. Every wrong answer on the sheet is what you get if you make one specific mistake.

So this workbook isn't about teaching you math. It's about teaching you the **sequence** — the exact order of operations for each of the five calculation families that show up on every journeyman and master exam in the country. Get the sequence right and the arithmetic takes care of itself.

Eighteen practice problems, all worked out. Eight more in a mixed set at the end, because on the real exam nobody tells you which calculation you're looking at.

Work them with a pencil. Reading them doesn't count.

— The Oakwood Press Team

Read This First

On the tables. Every one of these calculations requires you to look something up. Ampacity tables, conduit and conductor dimension tables, motor full-load current tables, transformer protection tables — those live in the NEC, they're copyrighted by the NFPA, and they are not reproduced in this document.

What you'll see instead is the *method*, with worked examples that state the individual values pulled from each table so you can follow the arithmetic. That's deliberate. The lookup is a ten-second skill. The sequence is the thing worth learning, and it's the thing exams actually test.

On editions. The values used here reflect the 2026 NEC. Note that the 2026 edition relocated Article 220 to **Article 120** and made other structural changes — but the calculation tables themselves (Chapter 9, Table 310.16, the motor tables, Table

450.3(B)) were not substantively changed. Confirm your exam's adopted edition before you study.

On the work. Nothing here replaces the Code, and nothing here replaces your judgment or your license. Verify before you install.

How To Use This

If you have an exam in under a month:

One chapter per day, six days. Work every example with a pencil — cover the solution, solve it, then compare. On day seven, do the mixed set at the end cold and time yourself at 4 minutes per problem.

If you have longer:

Same order, but redo the practice problems a week later. Calculation skill decays fast and rebuilds fast.

If you're in the field and just want to stop second-guessing yourself:

Read the "Where People Lose Points" box in each chapter first. That's the concentrated version.

The Method: Why Calculation Questions Are Easier Than They Look

Five habits. They apply to all six chapters.

1. Identify the calculation before you touch the numbers.

Read the question and name it: *this is an ampacity problem, this is a fill problem*. Exams mix the language deliberately. A question about "how many conductors fit" might be conduit fill or box fill depending on one word.

2. Write down what you're solving for.

Minimum conductor size? Maximum overcurrent device? Number of conductors? Percentage? Half of all wrong answers come from solving correctly for the wrong thing.

3. Order of operations is not optional.

Correction before adjustment. Table value before termination check. Conductor sizing before device sizing. When you shuffle the sequence you land on a plausible number that isn't the answer.

4. Know which direction you round.

Overcurrent devices usually round *up* to the next standard size — but not always, and the exceptions are where the points are. Conductors round up to the next size. Conductor counts round down, unless the decimal is 0.8 or greater.

5. Sanity-check the result against the physical world.

A 4/0 conductor on a 20A circuit is wrong even if your math says so. If the answer looks absurd, you inverted something.

CHAPTER 1

Ampacity

The calculation everything else depends on

Ampacity is first for a reason: conduit fill, voltage drop, and motor circuits all assume you've already established what the conductor can carry. Get this wrong and everything downstream is wrong too.

The core idea is simple. A conductor has a **table ampacity** based on its size, material, and insulation temperature rating. Then reality intervenes — the ambient is hot, or you've crowded the raceway — so you **correct** and **adjust** downward. Then the equipment you're landing on imposes its own ceiling.

Three separate limits. The answer is always the most restrictive one.

The Method

1. **Start at the insulation column.** Find your conductor in Table 310.16 at the temperature rating of the insulation — 90°C for THHN/THWN-2, 75°C for THW, 60°C for TW.
2. **Correct for ambient.** If the ambient is above 30°C (86°F), multiply by the correction factor from Table 310.15(B)(1), read from the same temperature column.
3. **Adjust for conductor count.** More than three current-carrying conductors in a raceway or cable? Multiply by the adjustment factor from Table 310.15(C)(1).
4. **Compare to the load.** The corrected and adjusted ampacity must be at least the calculated load.
5. **Apply the termination limit.** Per 110.14(C), the conductor's ampacity for load purposes cannot exceed the value in the terminal's temperature column — 60°C for equipment rated 100A or less, 75°C for equipment rated over 100A, unless marked otherwise.
6. **Apply the small conductor rule.** 240.4(D) caps overcurrent protection at 15A for 14 AWG copper, 20A for 12 AWG, 30A for 10 AWG.
7. **Size the overcurrent device.** Next standard size up per 240.4(B) where permitted, subject to the 800A ceiling.

The adjustment factors (Table 310.15(C)(1)) are worth memorizing outright:

- 4-6 conductors — 80%
- 7-9 conductors — 70%
- 10-20 conductors — 50%
- 21-30 conductors — 45%
- 31-40 conductors — 40%
- 41 and above — 35%

Worked Example 1.1 — Straightforward correction

Three 8 AWG THWN-2 copper conductors in EMT. Ambient 40°C. 75°C terminations. The load is 40A, noncontinuous. Is the conductor adequate, and what breaker?

Step 1 — Table value. THWN-2 is a 90°C insulation. 8 AWG copper at 90°C = **55A**.

Step 2 — Ambient correction. 40°C falls in the 36-40°C band. Correction factor at the 90°C column = **0.91**.

$$55 \times 0.91 = 50.05A$$

Step 3 — Adjustment. Three current-carrying conductors. No adjustment required.

Step 4 — Compare to load. 50.05A $\geq$ 40A. ✓

Step 5 — Termination limit. Terminations are 75°C. 8 AWG copper at 75°C = **50A**. The load of 40A is below that. ✓

Step 6 — Small conductor rule. Doesn't apply to 8 AWG.

Answer: 8 AWG is adequate. **40A overcurrent device**.

Note what happened in step 5. You were allowed to start at the 90°C column for the correction math, but you could never actually load the conductor above the 75°C value. That's the rule people misunderstand — the 90°C rating is a derating allowance, not a capacity gain.

Worked Example 1.2 — When adjustment and the small conductor rule collide

Six 10 AWG THHN copper current-carrying conductors in a single conduit. Ambient 30°C. The equipment is rated 100A with 60°C terminations. What is the maximum overcurrent device?

Step 1 — Table value. 10 AWG copper at 90°C = **40A**.

Step 2 — Ambient correction. 30°C is the table's base. Factor = **1.00**. Still 40A.

Step 3 — Adjustment. Six current-carrying conductors → **80%**.

$$40 \times 0.80 = 32\text{A}$$

Step 4 — Termination limit. Equipment rated 100A or less with 60°C terminations.
10 AWG copper at 60°C = **30A**.

Step 5 — Small conductor rule. 240.4(D) caps 10 AWG copper at **30A** regardless.

Answer: 30A.

Three separate limits produced three different numbers — 32, 30, and 30. The answer is the smallest. Notice that the derating you spent time on wasn't even the binding constraint. That's common, and it's why you check all three.

Worked Example 1.3 — Exam grade: continuous load, hot ambient, crowded raceway

A 480V three-phase feeder supplies a 150A continuous load. Nine current-carrying THHN copper conductors share the raceway. Ambient 45°C. Terminations are 75°C. What is the minimum conductor size?

This one has two independent tests and the conductor has to pass both.

Test A — The continuous load rule at the termination column.

Feeder conductors must be sized at not less than 125% of the continuous load, evaluated at the termination temperature.

$$150 \times 1.25 = 187.5\text{A required at the } 75^\circ\text{C column}$$

Test B — The actual load against the corrected and adjusted ampacity.

Ambient 45°C falls in the 41–45°C band → 90°C correction factor **0.87**.

Nine current-carrying conductors → adjustment **70%**.

The result must be at least the actual 150A load.

Try 3/0 AWG copper:

- 75°C value = 200A. Against Test A's 187.5A → ✓ passes
- 90°C value = 225A. $225 \times 0.70 \times 0.87 = 137.0\text{A}$. Against the 150A load → ✗ fails

Try 4/0 AWG copper:

- 75°C value = 230A $\geq 187.5\text{A}$ → ✓
- 90°C value = 260A. $260 \times 0.70 \times 0.87 = 158.3\text{A} \geq 150\text{A}$ → ✓

Answer: 4/0 AWG copper.

If you had run only Test A you'd have answered 3/0 — and 3/0 is on the multiple-choice list, because that's the mistake the question is designed to catch.

Where People Lose Points

- **Applying the correction factor from the wrong column.** If you started at 90°C, read the correction factor from the 90°C column too. Mixing columns is the single most common ampacity error.
- **Forgetting that correction and adjustment multiply together.** They are not alternatives. Both apply, in sequence.
- **Loading a conductor at its 90°C value.** Almost nothing in the field has 90°C terminations.
- **Counting the equipment grounding conductor as current-carrying.** It isn't.
- **Counting a balanced neutral.** In a 3-wire single-phase circuit or a balanced 4-wire wye with mostly linear loads, the neutral is not counted. Where the load is majority nonlinear, it is.

Your Turn

1.1 Four 6 AWG THHN copper current-carrying conductors in a raceway. Ambient 35°C. 75°C terminations. What is the corrected and adjusted ampacity?

1.2 Twelve 12 AWG THHN copper current-carrying conductors in one conduit at 30°C ambient. What is the maximum overcurrent device permitted?

1.3 A 208V three-phase panel feeder carries a 90A continuous load. Six current-carrying THHN copper conductors, 40°C ambient, 75°C terminations. Minimum conductor size?

Answers

1.1 — 6 AWG at 90°C = 75A. Ambient 31-35°C at 90°C → 0.96. Four conductors → 80%.

$75 \times 0.96 \times 0.80 = \mathbf{57.6A}$. Termination check: 6 AWG at 75°C = 65A, so 57.6A governs. **57.6A**.

1.2 — 12 AWG at 90°C = 30A. No ambient correction. Twelve conductors → 50%.

$30 \times 0.50 = 15A$. The small conductor rule would allow 20A, but the adjusted ampacity is 15A. **15A**.

1.3 — Test A: $90 \times 1.25 = 112.5A$ at 75°C. Test B: ambient 40°C → 0.91; six conductors → 80%; must reach 90A.

Try 1 AWG: 75°C = 130A ≥ 112.5 ✓. 90°C = 145A; $145 \times 0.91 \times 0.80 = 105.6A \geq 90A$ ✓.

Try 2 AWG: $75^{\circ}\text{C} = 115\text{A} \geq 112.5$ ✓. $90^{\circ}\text{C} = 130\text{A}$; $130 \times 0.91 \times 0.80 = 94.6\text{A} \geq 90\text{A}$ ✓.

Try 3 AWG: $75^{\circ}\text{C} = 100\text{A} < 112.5$ ✗.

2 AWG copper.

CHAPTER 2

Conduit Fill

Area in, area out

Conduit fill is the most mechanical calculation in the book, which is why it's the one people should never get wrong — and the one they routinely do, because they skip a step that feels obvious.

You are doing exactly two things: totaling the cross-sectional area of everything going in, and comparing it to the area the raceway is allowed to give up.

The Method

8. **Determine the fill percentage** from Chapter 9, Table 1:
 - **1 conductor — 53%**
 - **2 conductors — 31%**
 - **Over 2 conductors — 40%**
 - **Nipples 24 in. or shorter — 60%** (Chapter 9, Note 4)
9. **Look up each conductor's area.** Insulated conductors come from Chapter 9, Table 5. Bare conductors come from Chapter 9, Table 8. Compact-stranded conductors have their own table.
10. **Total the areas.** Multiply each area by its quantity, then sum. Count *every* conductor, including neutrals and grounds.
11. **Go to Chapter 9, Table 4.** Find your raceway type, then read down the column matching your fill percentage.
12. **Select the first trade size** whose value equals or exceeds your total.

The shortcut: where every conductor in the raceway is the same size and same insulation type, Annex C gives you the answer directly — no arithmetic. Exams often reward knowing this exists.

The rounding rule (Chapter 9, Note 7): when you're solving for the *number* of conductors and the calculation produces a decimal of **0.8 or larger**, round up to the next whole conductor.

Worked Example 2.1 — The basic case

Four 12 AWG THHN current-carrying conductors plus one 12 AWG THHN equipment grounding conductor, in EMT. What trade size?

Step 1 — Fill percentage. Five conductors. Over 2 → **40%**.

Step 2 — Areas. 12 AWG THHN = **0.0133 sq in** each.

Step 3 — Total. $0.0133 \times 5 = \mathbf{0.0665 \text{ sq in}}$

Step 4 — Table 4, EMT, 40% column.

- $\frac{1}{2}$ in. EMT → 0.122 sq in

Step 5 — Compare. $0.122 \geq 0.0665$ ✓

Answer: $\frac{1}{2}$ in. EMT.

The EGC counts. It always counts for fill, even though it never counts as current-carrying for ampacity. Two different questions, two different answers, same conductor.

Worked Example 2.2 — Mixed conductor sizes

Three 3/0 AWG THHN, one 2 AWG THHN, and one 6 AWG THHN in EMT on a 30 ft run. What trade size?

Step 1 — Fill percentage. Five conductors, over 2, not a nipple → **40%**.

Step 2 — Areas from Table 5.

- 3/0 AWG THHN = 0.2679 sq in
- 2 AWG THHN = 0.1158 sq in
- 6 AWG THHN = 0.0507 sq in

Step 3 — Total.

- $0.2679 \times 3 = 0.8037$
- $0.1158 \times 1 = 0.1158$
- $0.0507 \times 1 = 0.0507$
- **Total = 0.9702 sq in**

Step 4 — Table 4, EMT, 40% column.

- $1\frac{1}{4}$ in. → 0.598 sq in — too small
- $1\frac{1}{2}$ in. → 0.814 sq in — too small
- 2 in. → 1.342 sq in — ✓

Answer: 2 in. EMT.

Worked Example 2.3 — The same conductors in a nipple

Identical conductors, but the run is an 18-inch nipple between two enclosures. What trade size?

Step 1 — Fill percentage. A raceway 24 in. or shorter is a nipple → **60%** of total area.

Step 2-3 — Total conductor area. Unchanged: **0.9702 sq in**

Step 4 — Table 4, EMT total areas at 60%.

- 1¼ in. EMT total area 1.496 → 60% = 0.898 sq in — too small
- 1½ in. EMT total area 2.036 → 60% = 1.222 sq in — ✓

Answer: 1½ in. EMT.

Same wire, one trade size smaller, purely because the run is under two feet. The reasoning is that a short run has neither the heat build-up nor the pulling friction of a long one. This comparison — the same conductors solved twice — is a favorite exam construction.

Where People Lose Points

- **Forgetting the ground.** Every conductor in the raceway counts toward fill, bare or insulated.
- **Using the wrong insulation.** 10 AWG THHN is 0.0211 sq in; 10 AWG XHHW is 0.0243 sq in. Same copper, different jacket, different answer.
- **Using the 40% column for a nipple** — or the 60% column for a run that turns out to be 26 inches.
- **Using the 40% column for two conductors.** Two conductors is 31%, and the drop surprises people. It accounts for the dead air space two round conductors leave between them.
- **Reading the wrong raceway sub-table.** EMT, IMC, RMC, and each PVC schedule all have different internal areas at the same trade size. PVC Schedule 80 is dramatically smaller than Schedule 40 at small trade sizes.

Your Turn

2.1 Nine 10 AWG THHN conductors in EMT. What trade size?

2.2 Two 4 AWG THHN conductors in a 20-inch RMC nipple. Which fill percentage applies, and why is it not 31%?

2.3 Three 2 AWG THHN and one 6 AWG THHN in EMT, 40 ft run. What trade size?

Answers

2.1 — Over 2 → 40%. 10 AWG THHN = 0.0211. $0.0211 \times 9 = \mathbf{0.1899 \text{ sq in.}}$

EMT 40%: $\frac{1}{2}$ in. = 0.122 (too small); $\frac{3}{4}$ in. = 0.213 ✓. **$\frac{3}{4}$ in. EMT.**

2.2 — 60%. The nipple rule in Chapter 9, Note 4 applies to any raceway 24 in. or shorter *regardless of conductor count*, and it's more permissive than the 31% two-conductor value. The nipple allowance governs.

2.3 — Over 2 → 40%. 2 AWG THHN = 0.1158; 6 AWG THHN = 0.0507.

$(0.1158 \times 3) + 0.0507 = 0.3474 + 0.0507 = \mathbf{0.3981 \text{ sq in.}}$

EMT 40%: 1 in. = 0.346 (too small); $1\frac{1}{4}$ in. = 0.598 ✓. **$1\frac{1}{4}$ in. EMT.**

CHAPTER 3

Box Fill

Counting units, not wires

Box fill trips people up because it is not a conductor count. It's a **unit** count, and several of the things you count aren't conductors at all.

The mental model that makes it click: every item in the box displaces a certain volume, and the Code expresses that volume as a multiple of one conductor's worth of space. So you count units, then multiply by the volume allowance for the relevant conductor size.

The Method

Count the units (314.16(B)):

What's in the box	Units
Each conductor entering the box and terminating or spliced inside	1 each
Each conductor passing through without splice or termination	1 each
A conductor looped through with at least twice the required free length	2
All equipment grounding conductors, together	1 total
An additional insulated or isolated EGC	1 more
One or more internal cable clamps	1 total
Each support fitting — fixture stud, hickey	1 each
Each yoke or strap-mounted device	2 each
Conductors originating and terminating inside the box (pigtails)	0
Wire connectors, external cable connectors, locknuts, bushings	0

Then apply the volume allowance (Table 314.16(B)):

- 18 AWG — 1.50 cu in
- 16 AWG — 1.75 cu in
- 14 AWG — 2.00 cu in
- 12 AWG — 2.25 cu in
- 10 AWG — 2.50 cu in
- 8 AWG — 3.00 cu in
- 6 AWG — 5.00 cu in

Three sizing conventions that matter with mixed sizes:

13. **Conductors** are counted at their own size.
14. **Clamps** and the **EGC group** are counted at the size of the **largest** conductor in the box.
15. **A device** is counted at the size of the largest conductor **connected to that yoke** — not the largest in the box.

Worked Example 3.1 — Single size

A box contains four 14/2 NM cables with internal clamps, and one duplex receptacle. What minimum box volume is required?

Item	Count	Units
Insulated conductors (4 cables × 2)	8	8
Equipment grounding conductors (4, all count as one)	4	1
Internal cable clamps	—	1
Duplex receptacle (one yoke)	1	2
Total units		12

12 units × 2.00 cu in (14 AWG) = **24 cu in**

Answer: 24 cubic inches minimum.

Worked Example 3.2 — Mixed sizes

A box contains two 12/2 NM cables and one 10/3 NM cable, internal clamps, a 20A duplex receptacle wired with the 12 AWG conductors, and a 30A receptacle wired with the 10 AWG conductors. What minimum volume?

Item	Units	Size used	Volume
12 AWG conductors (2 cables × 2)	4	12 AWG	$4 \times 2.25 = 9.00$
10 AWG conductors (1 cable × 3)	3	10 AWG	$3 \times 2.50 = 7.50$
All EGCs	1	largest = 10 AWG	$1 \times 2.50 = 2.50$
Internal clamps	1	largest = 10 AWG	$1 \times 2.50 = 2.50$
20A receptacle yoke	2	12 AWG connected	$2 \times 2.25 = 4.50$
30A receptacle yoke	2	10 AWG connected	$2 \times 2.50 = 5.00$
Total			31.00 cu in

Answer: 31 cubic inches minimum.

The two devices are counted at different sizes. That's the detail the question exists to test — the yoke follows the conductors landed on it, not the biggest wire in the box.

Worked Example 3.3 — Solving in reverse

A 22.5 cu in device box has internal cable clamps and will hold one duplex receptacle. How many 12 AWG conductors can enter and terminate in it?

Step 1 — Convert volume to units.

$$22.5 \div 2.25 = \mathbf{10 \text{ units available}}$$

Step 2 — Subtract the non-conductor units.

- Duplex receptacle yoke: 2
- Internal clamps: 1
- Equipment grounding conductors: 1
- **Subtotal: 4 units consumed**

Step 3 — Remainder.

$$10 - 4 = \mathbf{6}$$

Answer: 6 conductors — which is three 12/2 cables, or two 12/3 cables.

Where People Lose Points

- **Counting a device as one unit.** Every yoke is two. Two switches and a receptacle in one box is six units before a single wire is counted.
- **Counting each equipment grounding conductor separately.** All of them together are one unit. Four grounds is still one.

- **Counting pigtails.** A conductor that begins and ends inside the box adds nothing.
- **Counting the wire nuts.** They aren't counted. Neither are external cable connectors.
- **Forgetting the clamp unit** on boxes with internal clamps — and *adding* one on boxes without them.
- **Using the box's stamped volume when a plaster ring is installed.** Extension rings and plaster rings are marked with their own volume, and that volume adds.

Your Turn

3.1 A box has three 14/3 NM cables with internal clamps, and two single-pole switches. Minimum volume?

3.2 A box has two 12/2 NM cables entering and terminating, one 12/2 passing straight through unspliced, no internal clamps, and one duplex receptacle. Minimum volume?

3.3 How many 14 AWG conductors may enter and terminate in an 18.0 cu in box containing internal clamps and one duplex receptacle?

Answers

3.1 — Conductors: 3 cables $\times$ 3 = 9. EGCs: 1. Clamps: 1. Two switch yokes: 4.

Total = **15 units** $\times$ 2.00 = **30.0 cu in.**

3.2 — Conductors terminating: 2 cables $\times$ 2 = 4. Conductor passing through: 2 more (one per conductor). EGCs: 1. Clamps: 0. Device: 2.

Total = 4 + 2 + 1 + 0 + 2 = **9 units** $\times$ 2.25 = **20.25 cu in.**

3.3 — $18.0 \div 2.00 = 9$ units. Device 2 + clamps 1 + EGC 1 = 4 consumed. $9 - 4 = 5$ **conductors.**

CHAPTER 4

Voltage Drop

The one that isn't a Code requirement — and gets asked anyway

Worth saying plainly: the 3% branch-circuit and 5% total figures everybody quotes come from Informational Note material. They are **recommendations**, not enforceable requirements, unless your jurisdiction amended them in.

Exams ask about them constantly anyway, and so do customers with a dimming problem at the end of a long run. Learn it.

The Formulas

Single phase:

$$> VD = (2 \times K \times I \times D) \div CM$$

Three phase:

$$> VD = (1.732 \times K \times I \times D) \div CM$$

Where:

- **VD** = voltage drop, in volts
- **K** = resistivity constant — **12.9** for copper, **21.2** for aluminum
- **I** = current, in amperes
- **D** = **one-way** distance, in feet
- **CM** = conductor area in circular mils, from Chapter 9, Table 8

To solve for conductor size instead, rearrange:

$$> CM = (2 \times K \times I \times D) \div VD \text{ (single phase)}$$

>

$$> CM = (1.732 \times K \times I \times D) \div VD \text{ (three phase)}$$

To express as a percentage:

$$> \% \text{ drop} = (VD \div \text{source voltage}) \times 100$$

Circular mil values you'll use most (Chapter 9, Table 8):

AWG	Circular mils
14	4,110
12	6,530
10	10,380
8	16,510
6	26,240
4	41,740
3	52,620
2	66,360
1	83,690
1/0	105,600
2/0	133,100
3/0	167,800
4/0	211,600

Above 4/0, circular mils equal the kcmil rating times 1,000 — a 250 kcmil conductor is 250,000 circular mils.

Worked Example 4.1 — Find the drop

A 120V single-phase circuit carries 16A to a load 150 ft away, wired in 12 AWG copper. What is the voltage drop, and what percentage?

Step 1 — Plug in.

$$VD = (2 \times 12.9 \times 16 \times 150) \div 6,530$$

Step 2 — Numerator.

$$2 \times 12.9 = 25.8$$

$$25.8 \times 16 = 412.8$$

$$412.8 \times 150 = \mathbf{61,920}$$

Step 3 — Divide.

$$61,920 \div 6,530 = \mathbf{9.48 \text{ volts}}$$

Step 4 — Percentage.

$$9.48 \div 120 = 0.079 \rightarrow \mathbf{7.9\%}$$

Answer: 9.48 V, or 7.9% — more than double the 3% guideline.

The conductor is perfectly legal on ampacity. 12 AWG on a 20A circuit is fine. Voltage drop is a separate question entirely, and distance is what kills you.

Worked Example 4.2 — Find the conductor

Same circuit — 120V, 16A, 150 ft, copper. What size conductor holds the drop to 3% or less?

Step 1 — Convert the percentage to volts.

$$120 \times 0.03 = \mathbf{3.6 \text{ V maximum}}$$

Step 2 — Solve for circular mils.

$$\text{CM} = (2 \times 12.9 \times 16 \times 150) \div 3.6$$

$$\text{CM} = 61,920 \div 3.6 = \mathbf{17,200 \text{ circular mils}}$$

Step 3 — Table 8.

- 8 AWG = 16,510 CM — too small
- 6 AWG = 26,240 CM — ✓

Answer: 6 AWG copper.

Note the numerator is identical to Example 4.1. Once you've computed $2 \times K \times I \times D$, both versions of the problem are one division away.

Worked Example 4.3 — Three phase, with an ampacity cross-check

A 480V three-phase feeder carries 100A to a panel 400 ft away. Copper conductors, 75°C terminations, noncontinuous load. Size the conductor for a maximum 3% drop.

Step 1 — Maximum volts.

$$480 \times 0.03 = \mathbf{14.4 \text{ V}}$$

Step 2 — Solve for circular mils.

$$1.732 \times 12.9 = 22.343$$

$$22.343 \times 100 = 2,234.3$$

$$2,234.3 \times 400 = \mathbf{893,712}$$

$$893,712 \div 14.4 = \mathbf{62,063 \text{ circular mils}}$$

Step 3 — Table 8.

- 3 AWG = 52,620 CM — too small
- 2 AWG = 66,360 CM — ✓

Step 4 — Cross-check ampacity. 2 AWG copper at 75°C = 115A ≥ 100A ✓

Answer: 2 AWG copper — satisfies both voltage drop and ampacity.

Now change one word. If that 100A load were continuous, you'd need 125A of ampacity at the termination column, and 2 AWG at 115A would fail. You'd go to 1 AWG. Voltage drop sizing never overrides the ampacity requirement — you take whichever conductor is larger.

Where People Lose Points

- **Using round-trip distance.** The formula already accounts for both conductors — that's what the 2 and the 1.732 are doing. Enter the **one-way** run.
- **Using 2 on a three-phase circuit.** Three phase uses 1.732.
- **Using the copper K value for aluminum.** 12.9 vs 21.2 is a 64% difference and it will not look wrong on your calculator.
- **Comparing drop to the wrong voltage.** A 208V three-phase circuit is measured against 208, not 120.
- **Sizing for voltage drop and forgetting ampacity.** Or the reverse. Both tests, every time; the bigger conductor wins.
- **Forgetting to upsize the equipment grounding conductor.** When you increase conductors for voltage drop, 250.122(B) requires the EGC to be increased proportionally in circular mil area. This gets missed constantly.

Your Turn

4.1 A 240V single-phase circuit carries 30A, 200 ft one way, in 8 AWG copper. What is the voltage drop percentage?

4.2 A 208V three-phase feeder carries 60A, 300 ft one way, copper. Size the conductor for 3% maximum.

4.3 A 120V single-phase circuit carries 12A, 175 ft one way, in 10 AWG **aluminum**. What is the drop in volts?

Answers

4.1 — $VD = (2 \times 12.9 \times 30 \times 200) \div 16,510 = 154,800 \div 16,510 = \mathbf{9.38\ V}$.

$9.38 \div 240 = \mathbf{3.9\%}$.

4.2 — Max volts: $208 \times 0.03 = 6.24$ V.

CM = $(1.732 \times 12.9 \times 60 \times 300) \div 6.24 = 402,170 \div 6.24 = \mathbf{64,450\text{ CM}}$.

Table 8: 3 AWG = 52,620 (too small); 2 AWG = 66,360 ✓. **2 AWG copper.**

(Ampacity check: 2 AWG at 75°C = 115A $\geq$ 60A ✓)

4.3 — VD = $(2 \times 21.2 \times 12 \times 175) \div 10,380 = 89,040 \div 10,380 = \mathbf{8.58\text{ V}}$ — about 7.2%.

Swap in copper and the same run drops 5.22 V. That's the K value doing all the work.

CHAPTER 5

Motor Calculations

Two different currents, doing two different jobs

Motor problems have a reputation for being the hardest thing on the exam. They aren't hard — they're just built on one distinction that, once you have it, unlocks everything.

There are two current values for every motor, and they are not interchangeable.

- **FLC** — the full-load current from Table 430.247 (DC), 430.248 (single-phase), or **430.250 (three-phase)**. This is a standardized table value. Use it for **conductors, branch-circuit protection, and disconnects**.
- **FLA** — the actual full-load amperes stamped on the **nameplate**. Use it for **overload protection only**.

Why the split? Because nameplate current varies by manufacturer, efficiency, and power factor. If conductors were sized off nameplate, replacing a motor could invalidate the circuit. The table standardizes the infrastructure. The nameplate protects the specific machine sitting there.

The Method

What you're sizing	Basis	Multiplier	Section
Branch-circuit conductors, single motor	Table FLC	125%	430.22
Overload protection	Nameplate FLA	125% or 115%	430.32
Branch-circuit short-circuit & ground-fault protection	Table FLC	Table 430.52	430.52
Disconnecting means	Table FLC	115%	430.110
Feeder conductors, multiple motors	Table FLC	125% largest + sum of others	430.24
Feeder overcurrent protection	—	Largest branch OCPD + sum of other FLCs	430.62

Overload sizing (430.32). 125% of nameplate FLA for motors with a service factor of 1.15 or greater, or a temperature rise of 40°C or less. **115%** for everything else.

Branch-circuit protection (Table 430.52). Maximum percentages of FLC for a typical squirrel-cage motor:

- Non-time-delay fuse — **300%**
- Dual-element (time-delay) fuse — **175%**
- Instantaneous trip breaker — **800%**
- Inverse time breaker — **250%**

Where the calculated value doesn't land on a standard rating, **430.52(C)(1)**

Exception No. 1 permits the next higher standard size.

Those percentages look absurd until you remember what they're protecting against. A motor draws six to eight times its running current on startup. The branch-circuit device has to sit through that inrush without opening. It isn't protecting the motor from overload — the separate overload device does that. It's protecting the circuit from a short.

Worked Example 5.1 — Single motor, complete

A 25 HP, 460V, three-phase squirrel-cage motor. Nameplate FLA is 32A, service factor 1.15. Copper THHN, 75°C terminations. Protection is dual-element time-delay fuses. Size the conductors, the overload, the fuses, and the disconnect.

Step 1 — Table FLC. From Table 430.250, a 25 HP motor at 460V three-phase = **34A**.

Step 2 — Branch-circuit conductors (430.22).

$34 \times 1.25 = \mathbf{42.5A}$ required

8 AWG copper at 75°C = 50A ✓

8 AWG.

Step 3 — Overload protection (430.32). Service factor is 1.15, so 125% — and this one uses the **nameplate**, not the table.

$32 \times 1.25 = \mathbf{40A}$

Step 4 — Branch-circuit short-circuit and ground-fault protection (430.52).

Dual-element time-delay fuse → 175% of the **table FLC**.

$34 \times 1.75 = 59.5A$

59.5 is not a standard size → next standard size up per 430.52(C)(1) Ex. 1 = **60A**

Step 5 — Disconnecting means (430.110).

$34 \times 1.15 = 39.1\text{A} \rightarrow$ a **60A** disconnect is the practical selection.

Answer: 8 AWG conductors · 40A overload · 60A time-delay fuses · 60A disconnect.

Note step 3 is the only one that touched the nameplate. Every other number came from the table.

Worked Example 5.2 — Same motor, inverse time breaker

Same 25 HP, 460V motor, but protected by an inverse time circuit breaker. What size breaker?

Table 430.52, inverse time breaker $\rightarrow$ **250%** of FLC.

$$34 \times 2.50 = \mathbf{85A}$$

85A is a standard rating per 240.6(A), so no rounding is needed.

Answer: 85A inverse time breaker.

Compare to the 60A fuse in the previous example. Same motor, same conductors, wildly different device rating — because a time-delay fuse tolerates inrush differently than a thermal-magnetic breaker. Neither one is the overload device.

Worked Example 5.3 — Exam grade: a feeder for several motors

One 25 HP and two 10 HP motors, all 460V three-phase, all protected by inverse time breakers. Copper, 75°C terminations. Size the feeder conductors and the feeder overcurrent device.

Step 1 — Table FLCs.

- 25 HP at 460V = **34A**
- 10 HP at 460V = **14A** each

Step 2 — Feeder conductors (430.24). 125% of the largest motor, plus 100% of the others.

$$(34 \times 1.25) + 14 + 14$$

$$= 42.5 + 28 = \mathbf{70.5A \text{ required}}$$

6 AWG copper at 75°C = 65A — too small

4 AWG copper at 75°C = 85A ✓

4 AWG copper.

Step 3 — Feeder overcurrent protection (430.62). The largest branch-circuit device, plus the full-load currents of the remaining motors.

- Largest branch device: $34 \times 2.50 = \mathbf{85A}$
- Plus the other FLCs: $14 + 14 = 28$
- $85 + 28 = \mathbf{113A}$

430.62 sets this as a value the feeder device **shall not exceed**. 113A is not a standard rating, and here you do **not** round up.

Next standard rating **at or below** 113A is **110A**.

Answer: 4 AWG feeder conductors, **110A** feeder overcurrent device.

This is the reversal that decides motor questions. Branch-circuit devices round up to the next standard size. Feeder devices are a ceiling — you round down. Both 110A and 125A will be on the answer sheet.

Where People Lose Points

- **Using nameplate FLA for conductors.** It's the table, every time — unless the motor is one of the special cases in 430.6 (multispeed, torque motors, motors under 1,200 rpm, etc.).
- **Using table FLC for the overload.** It's the nameplate, every time.
- **Applying 125% to every motor in a feeder.** Only the largest gets it.
- **Rounding a feeder device up.** 430.62 is a maximum.
- **Reading the wrong voltage column.** A 25 HP motor is 34A at 460V but 74.8A at 208V. Same horsepower, more than double the current.
- **Reading the wrong table.** Single phase is 430.248. Three phase is 430.250.

Your Turn

5.1 A 10 HP, 460V, three-phase motor with an inverse time breaker. Size the branch-circuit conductors and the breaker.

5.2 A 50 HP, 460V, three-phase motor. Nameplate FLA is 61A, temperature rise 40°C. Size the overload.

5.3 A feeder supplies one 30 HP and one 20 HP motor, both 460V three-phase, both on inverse time breakers. Size the feeder conductors and the maximum feeder overcurrent device.

Answers

5.1 — FLC = 14A. Conductors: $14 \times 1.25 = 17.5\text{A} \rightarrow 14 \text{ AWG at } 75^\circ\text{C} = 20\text{A} \checkmark$, so **14 AWG minimum** (most installers pull 12).

Breaker: $14 \times 2.50 = 35\text{A}$, a standard rating $\rightarrow$ **35A**.

5.2 — Temperature rise is 40°C , so 125% applies. Overload is based on nameplate.

$61 \times 1.25 = \mathbf{76.25A}$.

5.3 — FLCs: 30 HP = 40A, 20 HP = 27A.

Conductors: $(40 \times 1.25) + 27 = 50 + 27 = \mathbf{77A} \rightarrow 4 \text{ AWG at } 75^\circ\text{C} = 85\text{A} \checkmark$ **4 AWG**.

Feeder device: largest branch device = $40 \times 2.50 = 100\text{A}$; plus 27 = **127A** maximum.

127 isn't standard, and you round down $\rightarrow$ **125A**.

CHAPTER 6

Transformer Calculations

Find the current first, everything else follows

Transformer problems look intimidating and are mostly one formula plus one table. The reason people lose points is that they answer the wrong question: the Code protects the *transformer* in Article 450 and protects the *conductors* somewhere else entirely.

The Formulas

Single phase:

$$> I = VA \div E$$

Three phase:

$$> I = VA \div (E \times 1.732)$$

Run it once for the primary using primary voltage, once for the secondary using secondary voltage. Those two currents drive everything else.

Overcurrent Protection — Table 450.3(B), 1000V or Less

Primary protection only:

- Primary current 9A or more — **125%** of primary current
- Primary current less than 9A — **167%**
- Primary current less than 2A — **300%**

Primary and secondary protection:

- Primary — up to **250%** of primary current
- Secondary, 9A or more — **125%** of secondary current
- Secondary, less than 9A — **167%**

Note 1 to the table permits the next higher standard rating where 125% doesn't land on a standard size.

Worked Example 6.1 — Three phase, primary protection only

A 45 kVA transformer, 480V delta primary, 208Y/120V secondary, three phase. Size the primary overcurrent device using primary-only protection.

Step 1 — Primary current.

$$I = 45,000 \div (480 \times 1.732)$$

$$480 \times 1.732 = 831.4$$

$$45,000 \div 831.4 = \mathbf{54.1A}$$

Step 2 — Apply 125%. Primary current is above 9A.

$$54.1 \times 1.25 = \mathbf{67.6A}$$

Step 3 — Round. 67.6A isn't a standard rating. Note 1 permits the next higher standard size.

Answer: 70A primary overcurrent device.

Worked Example 6.2 — Same transformer, both sides protected

Same 45 kVA transformer. Now size both the primary and secondary devices, and the secondary conductors.

Step 1 — Secondary current.

$$I = 45,000 \div (208 \times 1.732)$$

$$208 \times 1.732 = 360.3$$

$$45,000 \div 360.3 = \mathbf{124.9A}$$

Step 2 — Primary device. With secondary protection in place, the primary may go up to 250%.

$$54.1 \times 2.50 = 135.3A \text{ — this is a ceiling, so the largest standard device at or below it is } \mathbf{125A}.$$

Step 3 — Secondary device. 125% of secondary current.

$$124.9 \times 1.25 = 156.1A \rightarrow \text{Note 1 permits the next standard size up} = \mathbf{175A}$$

Step 4 — Secondary conductors. Sized to the calculated load, minimum 125% of secondary current for a continuous rating.

$$124.9 \times 1.25 = 156.1A \rightarrow 2/0 \text{ AWG copper at } 75^{\circ}\text{C} = 175A \checkmark$$

Answer: 125A primary · 175A secondary · 2/0 AWG copper secondary conductors.

Worked Example 6.3 — The trap: what protects the secondary conductors?

A 480V to 208Y/120V three-phase transformer has primary overcurrent protection only. Do the secondary conductors need their own protection?

Yes. And this is the single most misunderstood point in transformer work.

Article 450 protects the **transformer**. It says nothing about the conductors leaving it. Secondary conductor protection is governed by **240.21(C)**, and the options are narrow:

- **240.21(C)(1)** — the primary device is permitted to protect the secondary conductors **only** for a single-phase transformer with a 2-wire primary and 2-wire secondary, where the primary protection is sized using the voltage ratio. This does not apply to a three-phase secondary.
- **240.21(C)(2)** — the 10-foot secondary rule
- **240.21(C)(4)** — outside secondary conductors
- **240.21(C)(6)** — the 25-foot secondary rule

Answer: With a three-phase secondary, the primary device does not protect the secondary conductors. You need overcurrent protection at the secondary, or you must qualify under one of the tap rules in 240.21(C).

The reason is proportion. In a delta-wye transformer, current transforms differently on each phase relationship, and a fault on the secondary may not produce enough primary current to open the primary device before the secondary conductors are damaged.

Where People Lose Points

- **Forgetting the 1.732 on three-phase.** It's the difference between a right answer and one that's 73% too high.
- **Using primary voltage to find secondary current.** Each side uses its own voltage.
- **Rounding the 250% primary value up.** It's a maximum. Round down.
- **Rounding the 125% values down.** Note 1 permits going up to the next standard size, and exams test that you know it.
- **Assuming primary protection covers the secondary conductors.** It generally doesn't.
- **Confusing kVA with kW.** Transformer ratings are in kVA. Don't apply a power factor.

Your Turn

6.1 A 75 kVA transformer, 480V delta to 208Y/120V, three phase. Find primary and secondary full-load currents.

6.2 A 15 kVA single-phase transformer, 480V primary to 240V secondary. Size the primary device using primary-only protection.

6.3 Using the 75 kVA transformer from 6.1, size the secondary overcurrent device assuming both sides are protected.

Answers

6.1 — Primary: $75,000 \div (480 \times 1.732) = 75,000 \div 831.4 = \mathbf{90.2A}$.

Secondary: $75,000 \div (208 \times 1.732) = 75,000 \div 360.3 = \mathbf{208.2A}$.

6.2 — Primary current: $15,000 \div 480 = 31.25A$. Above 9A $\rightarrow$ 125%.

$31.25 \times 1.25 = 39.1A \rightarrow$ next standard size up = **40A**.

6.3 — $208.2 \times 1.25 = 260.3A \rightarrow$ not standard; Note 1 permits next size up = **300A**.

APPENDIX A

The Formula Sheet

Everything on one page. Copy it onto the back of a notebook.

Ampacity sequence

16. Table 310.16 value at the **insulation** temperature column
17. $\times$ ambient correction factor — Table 310.15(B)(1), **same column**
18. $\times$ conductor adjustment factor — Table 310.15(C)(1)
19. Compare to load
20. Cap at the **termination** column — 110.14(C)
21. Cap by small conductor rule — 240.4(D)

Adjustment factors: 4-6 $\rightarrow$ 80% $\cdot$ 7-9 $\rightarrow$ 70% $\cdot$ 10-20 $\rightarrow$ 50% $\cdot$ 21-30 $\rightarrow$ 45% $\cdot$ 31-40 $\rightarrow$ 40% $\cdot$ 41+ $\rightarrow$ 35%

Continuous load: conductor and device at 125% of continuous + 100% of noncontinuous

Small conductor rule: 14 AWG Cu $\rightarrow$ 15A $\cdot$ 12 AWG Cu $\rightarrow$ 20A $\cdot$ 10 AWG Cu $\rightarrow$ 30A

Conduit fill

Fill percentages: 1 conductor $\rightarrow$ 53% $\cdot$ 2 conductors $\rightarrow$ 31% $\cdot$ over 2 $\rightarrow$ 40% $\cdot$ nipple $\leq$ 24 in. $\rightarrow$ 60%

Total conductor area (Table 5 insulated, Table 8 bare) $\rightarrow$ compare to Table 4 column $\rightarrow$ first size that fits

Rounding: solving for conductor count, round up only at a decimal of 0.8 or greater

Shortcut: all same size and type $\rightarrow$ use Annex C directly

Box fill

Units: conductor in-and-terminating 1 $\cdot$ passing through 1 $\cdot$ looped with double free length 2 $\cdot$ all EGCs 1 $\cdot$ extra insulated EGC +1 $\cdot$ internal clamps 1 $\cdot$ each support fitting 1 $\cdot$ **each device yoke 2** $\cdot$ pigtails 0 $\cdot$ wire nuts 0

Volume allowances: 18 AWG 1.50 $\cdot$ 16 AWG 1.75 $\cdot$ 14 AWG 2.00 $\cdot$ 12 AWG 2.25 $\cdot$ 10 AWG 2.50 $\cdot$ 8 AWG 3.00 $\cdot$ 6 AWG 5.00 cu in

Mixed sizes: conductors at own size · clamps and EGC group at **largest in box** · device at largest **on that yoke**

Voltage drop

> **1 ϕ :** $VD = (2 \times K \times I \times D) \div CM$

>

> **3 ϕ :** $VD = (1.732 \times K \times I \times D) \div CM$

>

> **Solve for size:** $CM = (2 \text{ or } 1.732 \times K \times I \times D) \div VD$

K: 12.9 copper · 21.2 aluminum

D: one-way feet

Guideline: 3% branch, 5% total — recommendation, not requirement

Don't forget: upsize the EGC proportionally — 250.122(B)

Motors

FLC = table value → conductors, branch protection, disconnect

FLA = nameplate → overload only

- Conductors, single motor: **125%** of FLC
- Overload: **125%** of nameplate FLA ($SF \geq 1.15$ or rise $\leq 40^\circ C$), else **115%**
- Branch protection: non-time-delay fuse **300%** · dual-element fuse **175%** · instantaneous breaker **800%** · inverse time breaker **250%** — next size **up** permitted
- Disconnect: **115%** of FLC
- Feeder conductors: **125% of largest** FLC + sum of others
- Feeder device: largest branch device + other FLCs — round **down**

Transformers

> **1 ϕ :** $I = VA \div E$

>

> **3 ϕ :** $I = VA \div (E \times 1.732)$

Primary only: $\geq 9A \rightarrow 125\%$ · $< 9A \rightarrow 167\%$ · $< 2A \rightarrow 300\%$

Both sides: primary $\leq 250\%$ · secondary $\geq 9A \rightarrow 125\%$ · secondary $< 9A \rightarrow 167\%$

Secondary conductors: protected under 240.21(C), not Article 450

APPENDIX B

The Mixed Set

Eight problems, no chapter headings. On the real exam nobody tells you which calculation you're looking at — identifying it is half the work. Give yourself four minutes each.

M1. Five 8 AWG THHN copper current-carrying conductors in a raceway at 30°C ambient with 75°C terminations. What is the maximum overcurrent device?

M2. A box contains two 14/2 NM cables and one 14/3 NM cable, internal clamps, one duplex receptacle and one single-pole switch. What is the minimum box volume?

M3. Six 6 AWG THHN conductors in EMT. What trade size?

M4. A 30 HP, 460V three-phase motor on an inverse time breaker. What size branch-circuit conductors, copper at 75°C?

M5. A 277V single-phase lighting circuit carries 14A to a load 250 ft away in 10 AWG copper. What is the voltage drop percentage?

M6. A 30 kVA three-phase transformer, 480V primary. What is the primary full-load current?

M7. Three 1/0 AWG THHN and one 6 AWG THHN in a 22-inch EMT nipple. What trade size?

M8. A feeder supplies one 20 HP and one 15 HP motor, 460V three-phase, inverse time breakers. What is the maximum feeder overcurrent device?

Mixed Set — Answers

M1. 8 AWG at 90°C = 55A. No ambient correction. Five conductors → 80%: $55 \times 0.80 = 44\text{A}$. Termination check at 75°C: 8 AWG = 50A, so 44A governs. Next standard size at or below 44A per 240.4(B)... 44A is not standard; 240.4(B) permits the next size **up** here since it's not a multi-outlet receptacle circuit and stays under 800A → **45A**.

M2. Conductors: $(2 \times 2) + 3 = 7$. EGCs: 1. Clamps: 1. Two yokes: 4. Total = **13 units** $\times 2.00 = 26.0 \text{ cu in.}$

M3. Over 2 → 40%. 6 AWG THHN = $0.0507 \times 6 = 0.3042 \text{ sq in.}$ EMT 40%: 1 in. = 0.346 ✓ ($\frac{3}{4}$ in. = 0.213, too small). **1 in. EMT.**

M4. FLC = 40A. $40 \times 1.25 = 50\text{A}$. 8 AWG copper at $75^{\circ}\text{C} = 50\text{A} \checkmark$ **8 AWG**.

M5. $\text{VD} = (2 \times 12.9 \times 14 \times 250) \div 10,380 = 90,300 \div 10,380 = 8.70 \text{ V}$. $8.70 \div 277 = 3.1\%$.

M6. $30,000 \div (480 \times 1.732) = 30,000 \div 831.4 = 36.1\text{A}$.

M7. Nipple $\leq 24 \text{ in.} \rightarrow 60\%$. $1/0 \text{ THHN} = 0.1855 \times 3 = 0.5565$; 6 AWG = 0.0507. Total = **0.6072 sq in.** EMT total areas: 1 in. = 0.864 $\rightarrow 60\% = 0.518$ (too small); $1\frac{1}{4} \text{ in.} = 1.496 \rightarrow 60\% = 0.898 \checkmark$ **1¼ in. EMT**.

M8. FLCs: 20 HP = 27A, 15 HP = 21A. Largest branch device: $27 \times 2.50 = 67.5 \rightarrow$ next standard up = 70A. Plus other FLC: $70 + 21 = 91\text{A}$ maximum. Not a standard rating; round **down** $\rightarrow 90\text{A}$.

Where To Go From Here

If you worked all twenty-six problems and got most of them, you're ready. If you got the arithmetic right but kept picking the wrong table or the wrong direction to round, that's the more useful diagnosis — you know exactly what to drill.

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