Headphone Essentials 9:

Headphone Power Requirements

Note 1: this document is part of a instructional series. If you would like to start with more foundational information on acoustics and headphones, go to Headphone Essentials.

Note 2: I am absolutely the wrong person to be writing this unit. I have zero electrical/electronics background and am not a tinkerer. If I knew of any other document or even video covering this material in a layman-digestible manner, I'd simply point you there and be done with it. But, because I *don't* have the technical background, I've been forced to pick up a sort of non-rocket-scientist, practical working knowledge of the relevant aspects of the subject as it relates to headphones.

Getting started

Currently, headphones that have been created to maximize sound quality rather than convenience tend to be wired rather than wireless. Traditionally, they also tended to have power requirements that exceeded the output of a smartphone or computer. and so required a separate amplifier inserted between the phone or computer and the headphone. That trend shows signs of dying out, but many well-regarded headphones date from the previous era. So the question is whether any particular headphone also needs a separate amplifier just to achieve a usable loudness level.

This YouTube video by headphone reviewer DMS explains the fundamentals involved:

Fig. 1: DMS YouTube tutorial

DMS tells us that we need to consider both impedance and sensitivity. A headphone that's rated at 32 ohms impedance and 110 dB sensitivity is clearly in the smartphone or computer power range. A headphone that's rated at 600 ohms impedance and 90 dB sensitivity is clearly in the extra amplification needed category. It's the grey area in between that needs clarification.

First, we need some vocabulary. **Electricity** jargon can be off-putting. I find the following analogy helps me make sense of this stuff:

- **Amps/Current** is like the quantity of water flowing through a hose.
- **Volts** are like the water pressure from the tap that is forcing the water to move.
- **Impedance** is anything that restricts the water from moving, such as a narrow hose or pipe diameter or a kink in the hose. (Impedance for A/C power, resistance for D/C power.)
- **Watts** is the amount of work done by any combination of amps and volts to overcome impedance.

Watts are abbreviated as **W**, or **mW** for milliwatts. Volts are are abbreviated as **V**. **Amps** is the abbreviation of amperes (but is confusingly also the short form of amplifier). Impedance is measured in **ohms**, which is often indicated by the symbol **Ω** (omega or the long o sound in the Greek alphabet).

Sound is described using two vocabulary terms:

- **Sound pressure level**, or **SPL**, is essentially the loudness of a sound as measured via a microphone.
- **Decibel** or **dB** is a ratio expressing the difference between two loudnesses. Decibels common in endless variants. The most common measure for sound in this context is actually **dB_{SPL}** but the SPL subscript is often left out.

A quiet room is likely to measure at 30 dB or more; conversation is normally between 40 and 60 dB. Prolonged exposure to 85 dB over a single 8 hour day causes hearing damage. Traffic can reach 80-90 dB. A typical rock concert's loudness is 103 dB. Even a brief exposure to 120 dB causes hearing damage. Hearing damage is permanent. It interferes with daily life, let alone music listening, and often leads to tinnitus later in life.

High impedance mythology

Next, we need to debunk some pervasive myths regarding amplification:

Myth 1: High headphone impedance = hard to drive.

If anything, it's more the opposite. Planar magnetic headphones are typically low impedance, yet these are voltage gobblers and may well exceed a smartphone's or computer's typical 1 or 1.2 volt maximum capability.

Myth 2: High headphone impedance = better sound quality.

No correlation necessarily exists. This misunderstanding goes all the way back to the 20th century, before specialized headphone amps existed. Back then, you plugged a headphone into the headphone socket of a typical stereo receiver. And these were designed for a high impedance load, such as 300 or 600 Ω.

Myth 3: The more amplifier headroom the better.

Headroom means having a power source such as a standalone amplifier that can deliver more amps and volts than your headphone needs at your typical maximum loudness level. What having a generous amount of extra power can do — depending on the kind (topology) of amplifier — is keep the amount of power you actually use down within the maximum linearity, non-strain, non-distortion comfort zone of the amp. But beyond a certain level of overhead, you're not getting any benefit and may be losing the ability to make fine loudness adjustments, even at the lowest gain setting.

Myth 4: Ultra-low distortion + ultra-low SINAD numbers = better sound quality.

(Harmonic) distortion is one of the sound characteristics the human brain is least capable of perceiving. As I write this, the current craze of shopping for ultra-low distortion electronics is forcing designers to make design decisions that actually reduce overall sound quality. Even if your ears and brains could make such fine discriminations, no headphone exists that doesn't have orders of magnitude more distortion than even mediocre electronics. Any distortion from competent electronics is being swamped by the headphone.

Myth 5: class A amplifier topology is simply better than the other topologies.

This is over my head, but experts overwhelmingly agree that excellent results can be had from class A, class A-B, class D and probably other topologies.

Non-myth 1: a given number of dollars spent on a better headphone will buy you more sound quality than if spent on electronics.

Frequently correct. Headphones (and room loudspeakers) are by far the weakest link in the hardware chain of components in a playback system. That said, on to…

Non-myth 2: use a separate amp and DAC, instead of what's built into your smartphone or computer, to improve sound quality.

Frequently correct. There do exist competent, low-cost, relatively low impedance headphones that get little or no benefit from separate electronics. But the majority of quality headphones will reveal more of their potential sound quality with a well-engineered external amp and DAC. And this is true even for headphones that don't need amplification to reach your desired loudness level. However, the differences do tend to be subtle and can easily disappear entirely in the presence of background noise and/or poor recording quality.

Non-myth 3: some amps produce better results with a given pair of headphones than other amps (same with DACs).

Frequently correct. This is called *synergy* and unfortunately for the hobbyist is a real thing. When considering buying a particular amp for a particular headphone or headphone collection, look for a consensus of reviewers and/or experienced forum contributors that a particular pairing will be favourable. Better yet, buy a headphone that's known not to be amp picky.

Step 1. Find the headphone power specs

Fig. 1: (example) DT 770 Pro specs (source: https://europe.beyerdynamic.com/dt-770-pro.html)

To get started, you need the input power numbers from any headphone you're considering. Let's use the beyerdynamic DT 770 Pro 80 ohm as an example. Looking on the manufacturer's web site we find that it's sensitivity is 96 dB per mW (assume any number in dB units in headphone specs is the sensitivity). Normally, we'd find an impedance number there as well. But in this case the name of the headphone model provides the impedance value as being 80 ohms (Ω).

If possible, also determine whether the headphone model in question uses dynamic drivers or planar drivers.

Step 2. Find the amplifier power specs

Let's say you're looking into buying the venerable JDS Labs Atom. You go to the manufacturer's web site: https://jdslabs.com/product/atom-amp/. Click on the specs tab, then zero in on:

Output Impedance	0.1 Ω
Channel Balance	< 0.6 dB
Max Output @ 600Ω	125mW (8.68 VRMS)
Max Output @ 150Ω	502 mW (8.66 VRMS)
Max Output @ 32Ω	1 Watt (5.66 VRMS)

Fig. 2: (example) JDS Labs Atom power specifications detail

Very first thing to look at is the output impedance. Headphones are allowed to have relatively "big" impedance numbers like 32 or 300 ohms (Ω). But in most cases the smaller the amp's impedance number, the better. Anything 2 Ω or under is fine. Anything over is for specialized use. In this case it's a versatile 0.1 Ω. Now look at the other output numbers:

Max Output @ 600Ω = 125mW and 8.68 V
Max Output @ 150Ω = 502 mW and 8.68 V
Max Output @ 32Ω = 1 Watt (1000 mW) and 5.68 V

(Would that all manufacturers provided this much information.) We'll need these numbers in step 4, below.

Step 3. Determine your loudness preference

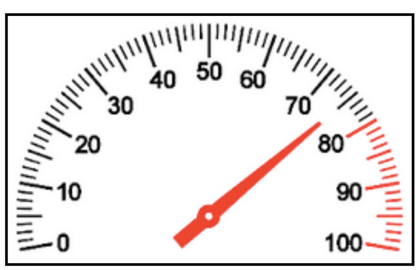

Fig. 3: typical sound meter app read-out (source: Google store)

Finally, as a one-time task, you need to determine how loud a listener you are. If you consider yourself a quiet/sensible loudness listener use 80 dB as a rough estimate for your peak/maximum loudness value. If you consider yourself an average loudness listener use 90 dB as your loudness value. Or use as high as 100 if you consider yourself a crazy-loud listener (or just want that capability available from time to time).

But it's relatively easy to get a more accurate number. There are free or inexpensive sound meter apps available for both Android and Apple smartphones. Just use one of these apps with the smartphone's lower end (where the microphone is) pressed to the ear cup of a headphone (or with the smartphone held up at listening distance from loudspeakers). Play a typical variety of music at the loudest level you would normally listen to. Simply make note of the peak or maximum loudness in dBs that shows in the app for each piece of music, then take an average of that. The only caveat here is to make sure the loudness number doesn't top out at some maximum level, like the one I used on my Android phone did.

Step 4. Calculate your power needs

Now you have everything you need to get some results. Go to the Apex HiFi page. Near the bottom is a spreadsheet. Click on that to save it to your computer, open it, then plug in the DT 770's 96 mW sensitivity number into the upper left green box, as shown in Fig. 4. Plug in the DT 770's 80 Ω impedance number into the green box just under it. Finally, plug in your peak loudness number from step 3 in the green Desired loudness box. I'll use a hefty 95 dB to illustrate the process. Now click in an empty cell to re-calculate. The resulting Required power and Required voltage numbers are what you want to see:

Headphone power calculator	
Headphone [sensitivity] (dBSPL @ 1 milliwat)	96
Headphone impedance (Ωs)	80
Desired loudness (dBSPL)	95
Required power (milliwatts)	0.79
Required voltage (volts RMS)	0.25
Required current (millamps RMS)	3.15

Fig. 4: Apex HiFi calculator with DT 770 numbers entered

The Atom's specs from Fig. 2 show 502 mW and 8.66 volts available at 150 Ω. So even more than that will be available at 80 Ω. Since 0.79 mW is far less than 502 and since 0.25 V is far less than 8.66, you're laughing.

But beyerdynamic headphones use technology (dynamic drivers) that doesn't have a constant impedance across the audible frequency range. The rated 80 Ω is likely to be the minimum impedance. The maximum impedance is unlikely to be more than twice the minimum, so plug in 160 into the impedance box in the spread sheet and re-calculate:

Headphone [sensitivity] (dBSPL @ 1 milliwat)	96
Headphone impedance (Ωs)	160
Desired loudness (dBSPL)	95
Required power (milliwatts)	0.79
Required voltage (volts RMS)	0.36
Required current (millamps RMS)	2.23

Fig. 5: Apex HiFi calculator with doubled impedance entered

The power stays the same at 0.79 mW but now the voltage changes slightly to 0.36. Still just a fraction of what the Atom has available. In fact, you should easily get your desired loudness from the vast majority of smartphones and computers.

Sensitivity: that headphone manufacturers are increasingly providing “sensitivity” as per volt numbers rather than per milliwatt is a useful thing. Per volt directly correlates with loudness. Per milliwatt does not. If headphone A has a sensitivity of 100 and headphone B has a sensitivity of 110, we know immediately that headphone B can produce more loudness than headphone A from the same number of volts — up to the volt output limit of the device.

Finally, notice the nearly duplicate set of spreadsheet cells below the ones you were using. Some headphone manufacturers provide sensitivity in terms of voltage rather than wattage. For example, Sennheiser is one such company. The classic open back HD 650 has an impedance of 300 Ω and a sensitivity of 103 db of SPL at 1 V. Using the same 95 dB for desired loudness we get:

Headphone sensitivity (dBSPL @ 1 volt RMS)	103
Headphone impedance (Ωs)	300
Desired loudness (dBSPL)	95
Required power (milliwatts)	1
Required voltage (volts RMS)	0.40
Required current (millamps RMS)	1.3

Fig. 6: Apex HiFi calculator with HD-600 numbers entered

Again, the Atom can easily do the job.

But let’s say you’re looking at a headphone that needs some serious power to operate. The Hifiman HE-560 has an impedance of a mere 45 Ω. But it has a very low sensitivity of 86 mW. If you want to be able to really crank up the volume from time to time, you can enter 100 as the desired dBSPL:

Headphone [sensitivity] (dBSPL @ 1 milliwat)	86
Headphone impedance (Ωs)	45
Desired loudness (dBSPL)	100
Required power (milliwatts)	25.12
Required voltage (volts RMS)	1.06
Required current (millamps RMS)	23.63

Fig. 7: Apex HiFi calculator with HE-560 numbers entered

Now we’re ‘way past phone and computer power territory with those 25 mW, but again the Atom is more than capable. Since the HE-560 uses planar magnetic, not dynamic driver technology, it’s impedance stays relatively constant. So we don’t need to check with a doubled impedance.

So what would it take to challenge this Atom amp? The most notorious power hog of all time seems to be the Hifiman HE-6. The web tells me this weighs in at 83.5 dB and 50 Ω impedance. Plugging those in and leaving the loudness at 100 the spreadsheet says 44.67 mW and 1.49 V. That’s still only a small fraction of the Atom’s capability. But if we want to push things up into instant-tinnitus territory we can change the desired loudness to 110. Now we're talking serious power: 446.68 mW at 4.73 V. Yet still well within the Atom's capacity.

But also notice the 10-fold jump in power from 44.67 mW at 100 dB loudness to 446.7 mW at 110 dB loudness. This beautifully illustrates how dangerous a thing loudness can be. Our ears (actually, our brains) tell us the extra 10 dB is more or less a subjective doubling of loudness. But the 10-fold increase in power tells us just how violent the gale is that we're subjecting our ear drums to. That of course is equally true for any 10 dB increase, whether from 70 to 80 dB or from 80 to 90. The science tells us that 85 dB is the very loudest sound level our ears are built to withstand for more than a brief exposure.

Another interesting aspect of the HE-6 is its combination of ultra-low sensitivity with very modest impedance. The standard mantra is that for technical reasons an amplifier's impedance should be no more than 1/8th the headphone's impedance. 1/8th the HE-6's 50 Ω is just over 6 Ω. So theory says that any amp with 6 Ω or less output impedance should work well. But such a large number could be worrying to people used to 2 Ω output impedance being on the high side. It's easy to think only in terms of headphone impedance plus sensitivity vs amp milliwatts and volts. But there are unusual headphones with unusually low impedances, like Mr Speaker's (now Dan Clark Audio's) 13 Ω Aeon Flow models. And there are headphone amps with unusually high output impedances, like the 100 Ω(!) beyerdynamic A 20. Turns out this can result in a bass-boost synergy with certain headphones.

Dealing with incomplete specs


A pervasive problem exists where only partial power output specs (typically, just the power with a 32 Ω load) are given. but higher a impedance headphone has to be used. Our headphone amp delivers an amazing 5 watts of power at 32 Ω! And we're left to either assume this same 5 watts is available at 150 Ω or 300 Ω or whatever. Or if we know a bit more about the subject we might then assume that the power scales linearly with an increased load. If we have a 300 Ω headphone, we might assume we'll get roughly 500 mW of power from the amp, which is still an excellent number. But this is far from a safe assumption.

Consider the Fulla amplifier. Schiit Audio lists its output very nicely as:

Maximum Power, 16 ohms: 300mW RMS
Maximum Power, 32 ohms: 200mW RMS
Maximum Power, 50 ohms: 150mW RMS
Maximum Power, 300 ohms: 40mW RMS

300 Ω is roughly 10x 32 Ω, but 40 mW is not 1/10th of 200 mW — surprisingly, it's actually more.

But another aspect of the incomplete specs problem is that even the Schiit specs tell us nothing about how the wattage is divided between amps and volts. An amplifier that is voltage constrained has a loudness ceiling that may or may not prove to be an issue. In the case of any Schiit product I'm not concerned that loudness would ever be a problem. But I don't know whether that applies to other companies.

Along this line, what are we to make of the IFi Hip DAC?

Power Output (@1% THD)	**BAL**: 400 mW @ 32 Ohm ; **S-BAL**(SE): 280 mW @ 32 Ohm **BAL**: 6.3 V @ 600 Ohm ; **S-BAL** (SE): 3.2 V @ 600 Ohm

If I were an electrical engineer, switching from milliwatts at 32 Ω to volts at 600 Ω might make perfect sense. But as a mere non-technical consumer, I'm left scratching my cranium. 3 and 6 volts are indeed impressive numbers. But what are the volt numbers at 32 Ω and what are the watt numbers at 600 Ω? A little knowledge is a dangerous thing. In this case, my little knowledge about electronics gets compounded by the little knowledge IFi's marketing department has chosen to dole out to me.

But even if manufacturers did routinely provide watts and volts at a useful range of ohm loads, that still only paints an incomplete picture. A competent electronics person would undoubtedly say that we need to see power graphs or some such more technical data.

Ultimately, the only way to get a real feel for whether a given amplifier is appropriate for your needs is to ask on a headphone enthusiast forum such as HiFi Guides.

Further reading/viewing

Shure:

Understanding Headphone/Earphone Specifications

NwAvGuy:

Headphone Impedance Explained

Headphone & Amp Impedance

Headphone Amps/DACs Explained

More Power?

All about Gain

Jay's Take:

https://www.youtube.com/watch?v=elsjRoOt8AM

Headphonesty:

Headphone Impedance Demystified: Do I Need a Headphone Amp?

Note: the Jay's Take video is an enjoyable flashback to the state of the headphone amplifier scene a mere five years ago, as I write this. He only mentions a few brands because so few brands existed, especially in the lower price brackets. A couple misconceptions: he uses the Sennheiser HD 650 as an example of a headphone that needs amplification just to get loud enough. This is due to the 650's 300 Ω input impedance. We've seen above that ohms alone tell us next to nothing about the load on the amplifier. If anything a higher ohm number means the amp will have an easier time. But back then this was almost universal mythology.

Then he posits that, because there exists classical music that is recorded 19 decibels below some normal level, you'll need a more powerful amp to listen to classical. The reason such compositions, or passages within larger compositions, are recorded at such a quiet level is because the composer scored them *pianissimo.* They are meant to be listened to at near-whisper level. Such a recording is a great test of the presence of background hiss, whether from the playback electronics or whether present in the recording. Such a recording is just the opposite of demonstrating a demand for higher amplifier power.

Finally, he suggests that the more budget options are deficient on power. This is only true if they're used for listening at ear-damaging loudnesses (over 85 decibels). If a Fulla or E10K isn't loud enough for an HD 650, your future self is screaming at you to turn down the volume and spare yourself the torment of tinnitus.