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Why I wrote this article:

There's been a bit of confusion across the internet with regards to the charging rates and capability of the Apple OEM USB-C chargers when used with the Apple MagSafe Charger. I've provided some data about how the MagSafe Charger performs with a number of Apple USB-C chargers as well as against a reference USB-C charger from Cambrionix. I haven't gone into enormous depth regarding the USB Power Delivery protocol and what happens 'under the hood' but hopefully the data provided will help you make your own decisions as to whether the MagSafe Charger is/isn't for you and whether the charger you already have will work effectively with it.
I'll also explore whether its better to charge your devices in the oven or the fridge!

The MagSafe Charger:

The MagSafe Charger connects to a USB-C charger via a USB-C cable/connector and provides wireless charging capability. Its compatible with the Qi wireless charging protocol but also supports proprietary wireless charging from Apple in order to sneak some extra power across the gap. The word 'charger' is used loosely since both the USB-C 'chargers' and the 'MagSafe Charger' are effectively both power supplies. The actual battery management and charging electronics are within the iPhone itself. This is a wise move since charging Li-Ion batteries can be a dangerous pastime if not done correctly. Leaving a peripheral to manage the process opens up rogue peripherals to do damage to the iPhone internal battery. But enough about that, back to the MagSafe Charger.
The MagSafe Charger is a nicely designed wireless charger which, if you have a newer iPhone 12, holds itself in place on the rear of the phone via integrated magnetics. This ensures that the wireless charging coil is placed parallel and centred with the opposing coil within the iPhone. It's a neat solution and at least removes one of the main issues with wireless charging which is poor alignment of the coils causing poor power transfer efficiency. There's data, as well as power, transferred between the MagSafe Charger and the iPhone 12 although I have not documented the communication (made possible via NFC). This communication can be used to identify the MagSafe compatible accessory stuck to the phone.
The MagSafe wireless charger retails for around $40 and requires a suitable USB-C charger in order to work at its best.

Why USB-C Power Delivery?

USB-C Power Delivery chargers take advantage of extra control channel signals within a USB-C connector/ cable. These extra control signals are only accessible by using a USB-C connector and appropriate cable. In essence, these control signals allow a charger to advertise its capabilities to a device and the device to tell the charger what it will accept. Other info changes hands between the charger and device, ACK's, vendor data etc but they are beyond the scope of this article.
USB PD 2.0 also allows for a number of different voltages and current limits to be advertised to the connected device: 5/9/15/20V, 2/3/5Amp etc. The advertised voltages depend on the power available from the charger. Power is calculated by multiplying the charger Voltage by the charger Current in Amps. For example, a charger offering 9V and 3Amps would be offering 27Watts (9x3=27).

- A charger offering more than 15Watts will advertise 5V and 9V.
- A charger offering more than 27Watts will advertise 5V, 9V and 15V.
- A charger offering more than 45Watts will advertise 5V, 9V, 15V and 20V.

In the case of a MagSafe Charger, it is looking for 9V at 2.22Amps which works out to be 9*2.22=20Watts. This 2.22Amps should be regarded as the minimum current that a compatible charger should offer at 9V. For info, all USB-C cables, according to the USB-C spec should be able to handle at least 3Amps. 5Amp cables require additional electronics in the form of an e-Marker and are designed for devices requiring over 60Watts such as some laptops. If you've got time on your hands and want to learn more about this then here's a link to a presentation on USB Power Delivery from USB.org:

https://usb.org/sites/default/files/D2T2-1%20-%20USB%20Power%20Delivery.pdf

PD2.0 or PD3.0 - what does MagSafe use?

During testing I captured the data packets between the USB-C charger and the MagSafe Charger. The data packets were only relating to Power Delivery spec version 2.0, rather than PD3.0. Is there a problem with this, no, although I expect to see Apple switch to PD3.0 across the board in the future so they can leverage the increased functionality within the PD3.0 spec. The 2018 MacBook Pro 'talks' PD3.0.
PD2.0 will work with a PD3.0 charger since PD3.0 is backwards compatible, but there are some additional features baked-into PD3.0 which can offer some benefits. Here are just a couple of them:

- PPS (Programmable Power Supply). This allows the charger and device to negotiate a voltage between 3.3V and 21V in 20mV steps. The device current limit can also be negotiated in 50mA steps. What this means is that if the internal device charging electronics work most efficiently (read: less heat generated) at say 4.4V then the device can request 4.4V.
- C-Auth (USB-C Authentication). This allows a charger or device to authenticate with each other, this is in addition to authenticating the e-marker in the cable between them. What this means is that it could be possible in the future that certain chargers could be 'blacklisted' or certain chargers may only work with certain devices. For example, an Apple device may only authenticate with Apple chargers or approved OEM chargers.

Wireless charging and the environment:

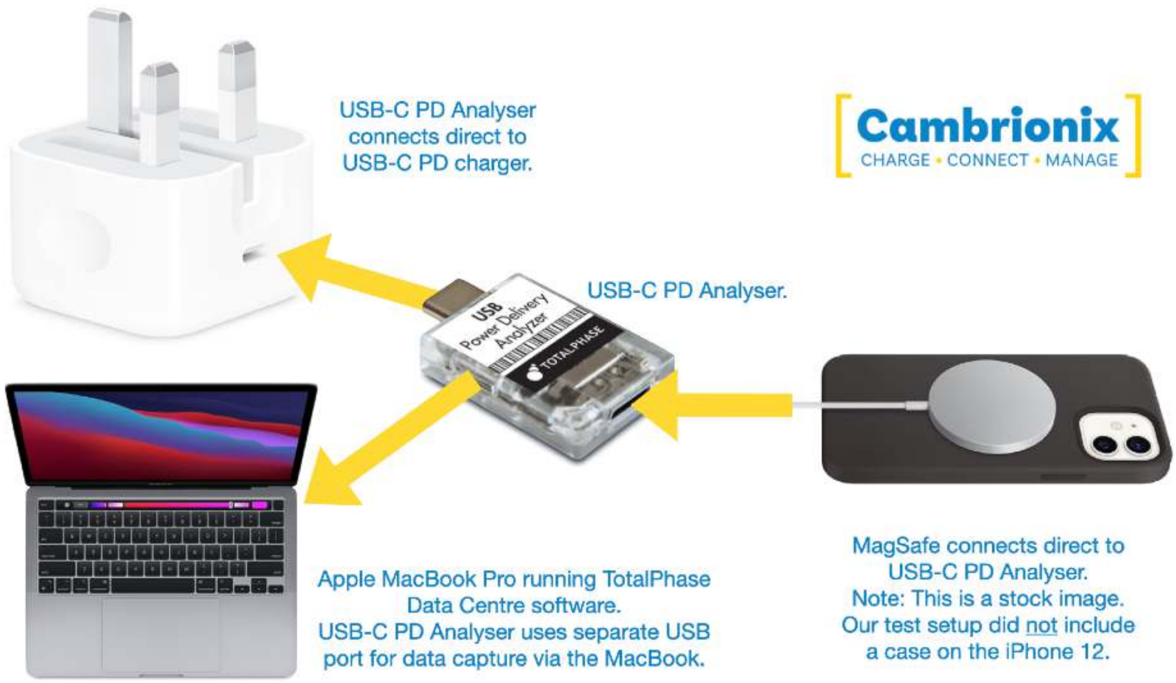
Wireless charging will never equal the efficiency/speed of wired charging and as a result is the least friendly to the environment both in terms of quantity of materials used and energy wasted as heat. Calculating the inefficiencies of wireless charging and multiplying this by the number of cellphone users in the world gives a very daunting figure in terms of wasted power, albeit a worst case scenario.
My view is that MagSafe Charger will not replace having a Lightning or USB-C connector on an Apple product - if it did then ultimately, over time each and every mobile Apple product would utilise it and each and every user would waste some additional Watt-Hours each time they charge their phone. This kinda goes against the world efforts to save energy.

How did I collect the data:

The data was collected using a commonly used USB PD Analyser which measures Vbus, Vconn, CC1 and CC2 voltage and current as well as capturing and decoding the USB PD data packets between the USB-C charger and MagSafe Charger. I have decided not to publish the data packets between the USB-C charger and MagSafe Charger since this would require me to explain what each of the data packets contains and what it does. Although I could do this, it doesn't help present the data which the article is about ie. How quickly does the MagSafe Charger charge an iPhone 12 from 0-100% with various USB-C chargers.

Collecting charging data was a long process. First I had to drive the battery level of the test phone (in this case an iPhone 12) down to the point where it doesn't boot. This takes many hours of streaming video, sound and flashlight! Once the battery is flat, I then charge it and record various parameters during the full charging run from zero to 100%. Each of the test runs I did ran for at least 4hrs and each test run created a CSV file with close to 2,000,000 rows, way in excess of the amount of data which Apple Numbers and Microsoft Excel can import. After some searching I found an app called DataGraph for MacOS which worked great when dealing with huge CSV files.

The image below shows how the test gear was hooked up.



Equipment used:

- TotalPhase USB PD Analyser.
- TotalPhase Data Centre software (v6.73.007).
- DataGraph software (v4.6.1) for large CSV files beyond the capability of Numbers/Excel.
- Micro-USB to USB-C cable to connect the PD Analyser to the host computer.
- Apple MacBook Pro 15” 2018 running MacOS BigSur (v11.0.1).
- Apple MagSafe Charger.
- Apple iPhone 12 without case.
- Apple 18W USB-C charger.
- Apple 20W USB-C charger.
- Apple 87W USB-C charger.
- Cambrionix PDSync-4 (240W across 4 USB-C ports).
- A household refrigerator.
- A household oven.
- ….a family willing to allow you to turn your kitchen into a makeshift test lab.

Things to note regarding the testing:

- Each test run creates a graph of Current over Time from zero to 100% charged. The graph title gives any specific details of the test run which are relevant.
- The iPhone had cellular and Bluetooth turned off and no SIM was fitted.
- Current and power measurements are measured to the MagSafe Charger and iPhone 12 as a ‘system’. I did not perform internal measurements within the iPhone 12 or MagSafe Charger. All measurements include power consumed and current drawn by both the MagSafe Charger and iPhone 12 combined.
- The same equipment was used for each test, only the USB-C charger changed between tests.
- There may be some inaccuracies within the data or unseen issues with the testing setup. The data is intended to form a comparison between a number of chargers using the same basic test setup.
- 2 Test runs (0-100% charged) were performed per USB-C charger.
- The PD Analyser includes 0.015 Ohm current measurement resistors which we have deemed to have minimal affect on the performance of the MagSafe Charger or the voltage measurements. Maximum Vdrop across the current measurement resistors at 3Amp (which is the maximum current the MagSafe Charger could negotiate with the USB-C charger) is 3Amp x 0.015 = 0.045V or 45mV. Additional voltage drop will be introduced via the USB-C connector contact resistance which is expected to be of a similar magnitude.
- Ambient temperature was 22deg C, iPhone 12 and MagSafe Charger were placed flat on a Corian work surface.
- Between test runs the battery on the iPhone 12 was fully depleted to the point where the iPhone would not boot. It was then left in this state to cool for at least 2 hours prior to the next test run.
- Battery optimisation was <u>disabled</u> on the iPhone 12.
- iPhone 12 was box-fresh and no iCloud login provided, no Siri enabled and no location services or cellular. Wifi was switched on during each test run. There were no background apps running.

Starting a charging test:

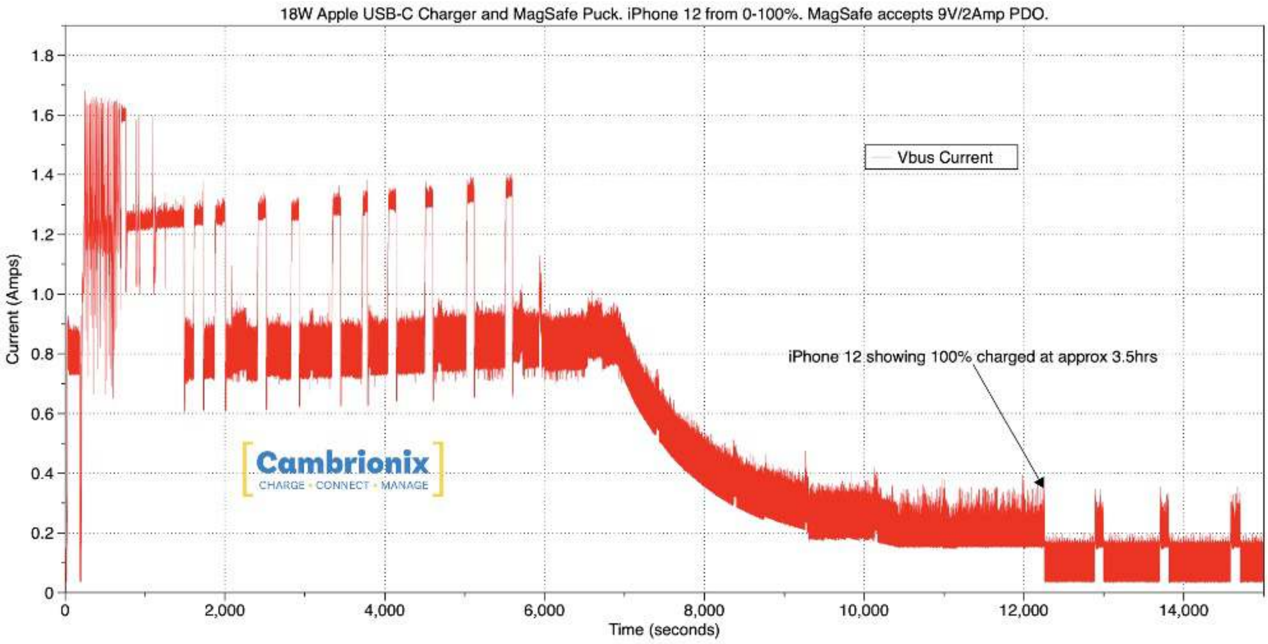
1. Force-close all running apps on the iPhone 12.
2. Discharge the iPhone 12 battery to zero percent charge. This is the point where the iPhone 12 will not boot. We found that running the flashlight, display brightness 100% and 4K video streaming over WiFi was the quickest way although the battery life is so good that this still takes an incredibly long time!
3. We then make sure the PD Analyser is connected to the MacBook and the analysis software is running.
4. Connect the PD Analyser to the USB-C charger.
5. Start the data capture.
6. Now connect the USB cable from the MagSafe Charger to the PD Analyser.
7. Some activity will be seen within the PD analysis software - this is the MagSafe Charger communicating with the USB-C charger and vice-versa. After a few seconds of comms the MagSafe Charger will accept the 9V PDO (Power Delivery Object) which will cause VBUS to rise from 5V to 9V.
8. Wait a few seconds as per Apple guidelines and then place the iPhone 12 on the MagSafe Charger. https://support.apple.com/en-gb/HT211829
9. At this point the current trace within the PD analysis software will start to increase.
10. Wait, and do not touch the phone unless absolutely necessary to check the percent charged level. Leave the phone on the MagSafe Charger at all times during the test.

The battery within the phone is deemed almost charged once the current trace curves downwards to a power level of around 1Watt or so (Note that this includes power being consumed by the iPhone and the MagSafe Charger). To calculate power, multiply the current (Amps) by the voltage level which, in the case of all the USB-C chargers tested, is 9V.
Once the power level starts to creep down its sensible to check the phone to see what the charge level is. If its under 100%, keep charging. When checking the battery percent I left the phone on the MagSafe Charger and tapped power button once to see the charge level. The iPhone was not unlocked and the screen only stayed illuminated for a few seconds.

So, that’s the equipment required along with a basic test method. Lets now take a look at the data which was captured. Oh, but first, please accept my apology to the whole internet for using the word ‘puck’ when referring to the MagSafe Charger on the graphs. I still think its strange to call it a charger and the charger it connects to also a charger. In my lowly opinion a better name may have been a MagSafe ‘Adaptor’ but hey, lets roll with ‘puck’ for the sake of the graphs!

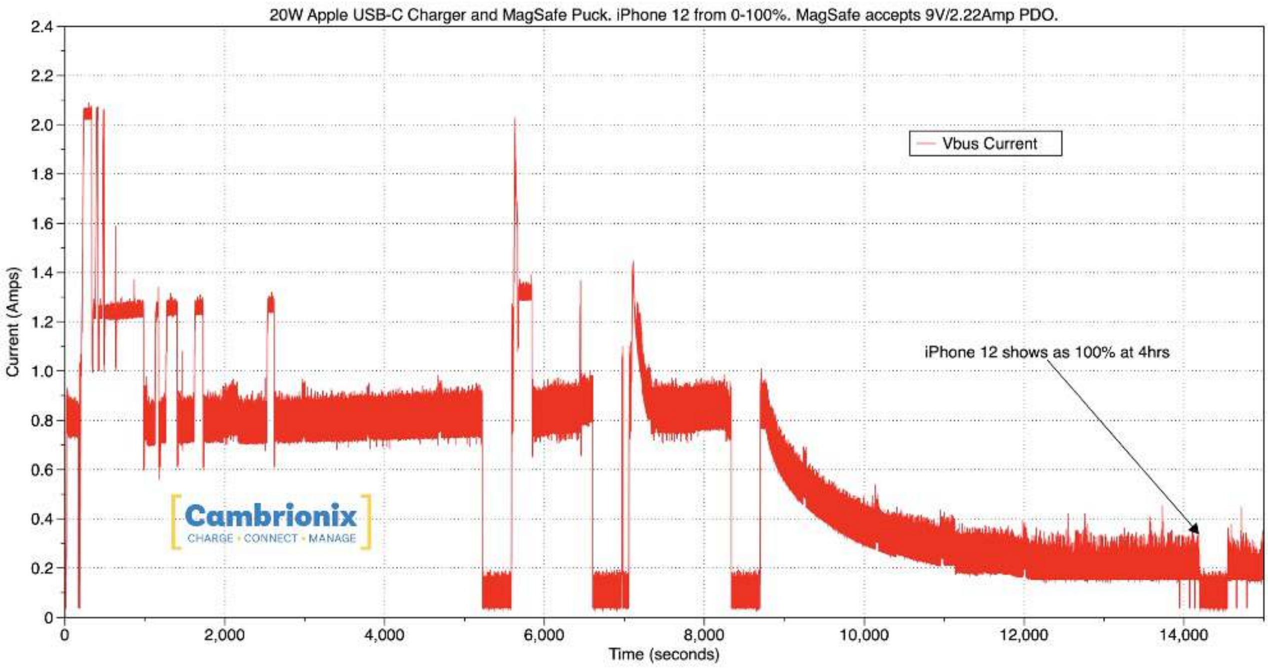
Apple 18W USB-C Charger:

The first charger on the list is the Apple 18W USB-C charger.
The MagSafe Charger accepts 9V at 2Amps (18W) from the USB-C charger and the iPhone shows as being fully charged after 3.5hrs. Ambient temp was 22deg C.
The MagSafe+iPhone takes 'gulps' of current centred around the 4,000 seconds mark. Maybe the current goes up and the iPhone monitors the change of internal temperature and cranks down the charging current if it rises?



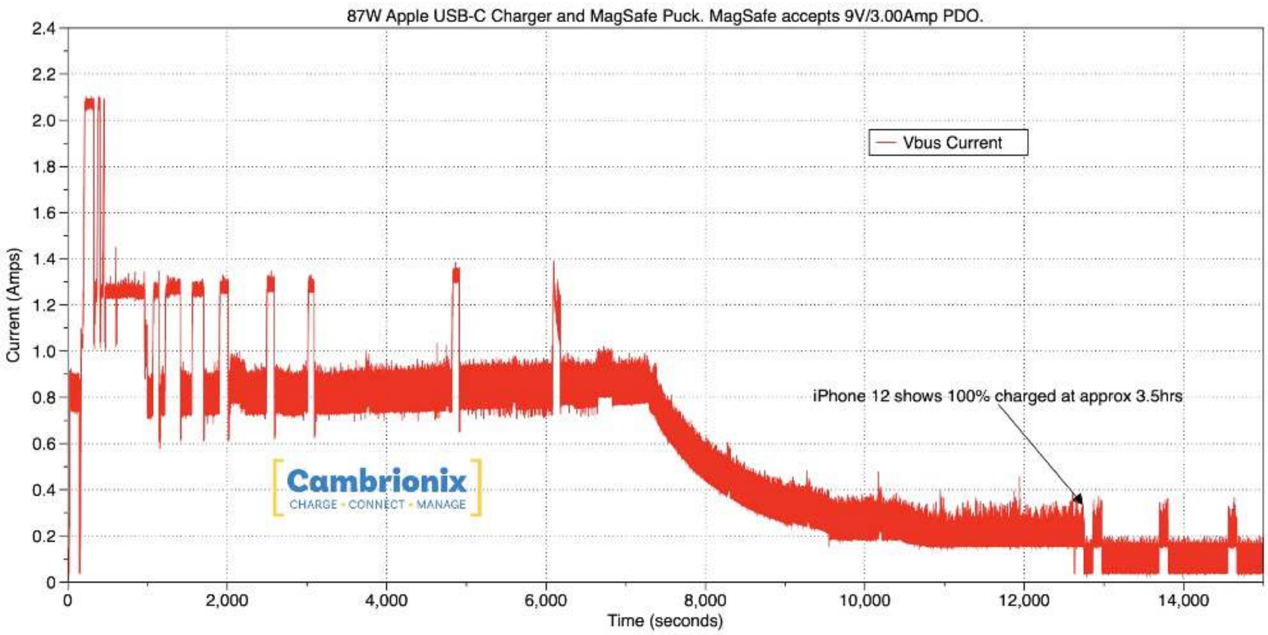
Apple 20W USB-C Charger:

This is the charger which is recommended for use with the MagSafe Charger. The iPhone 12 gets to 100% charged after 4hrs and the MagSafe Charger accepts 9V at 2.22Amps (20W) from the USB-C charger. Ambient temp was 22deg C.
Unusual drops in charging current shown here centred around the 7,000 seconds mark. These drops in current may be required to allow the iPhone or MagSafe Charger to cool.



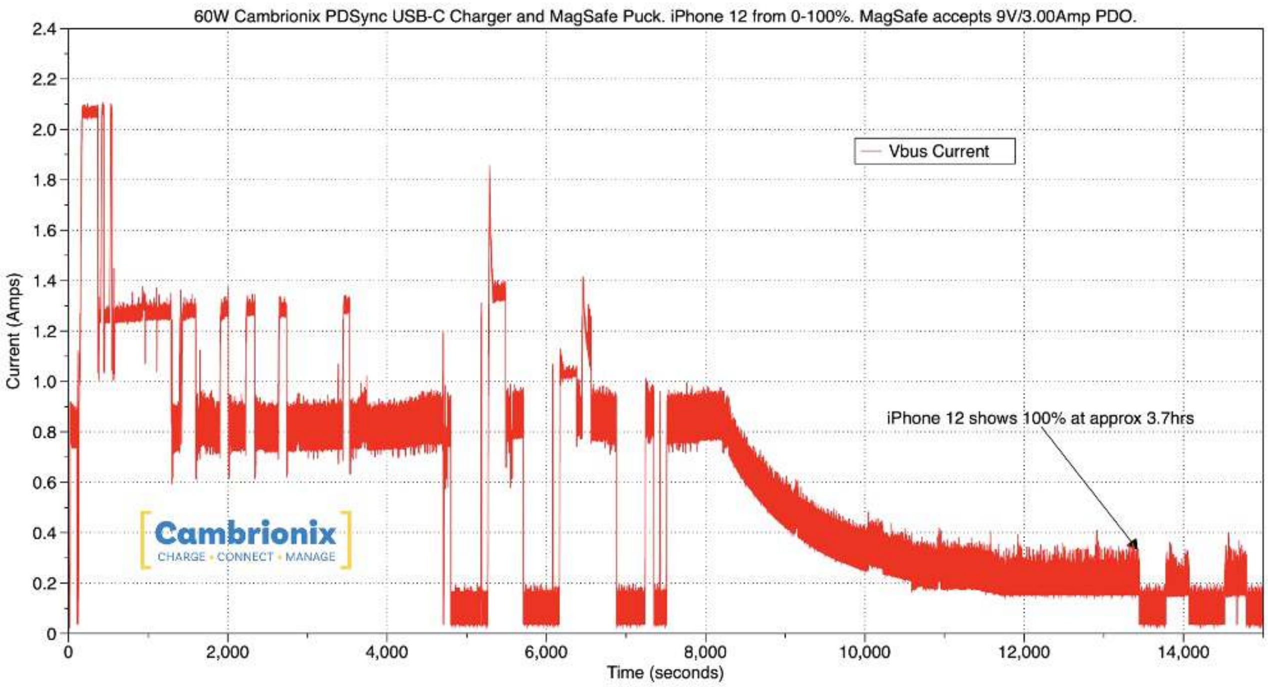
Apple 87W USB-C Charger:

iPhone 12 shows as 100% charged after 3.5hrs. MagSafe Charger accepts 9V at 3Amp (27W) from the USB-C charger. Ambient temp was 22deg C. The current profile is similar to the Apple 18W USB-C charger. Interestingly this USB-C charger advertises 5/9/20V to the MagSafe Charger. No option for 15V which is 1) Strange and 2) a possible diversion from the PD2.0 spec.



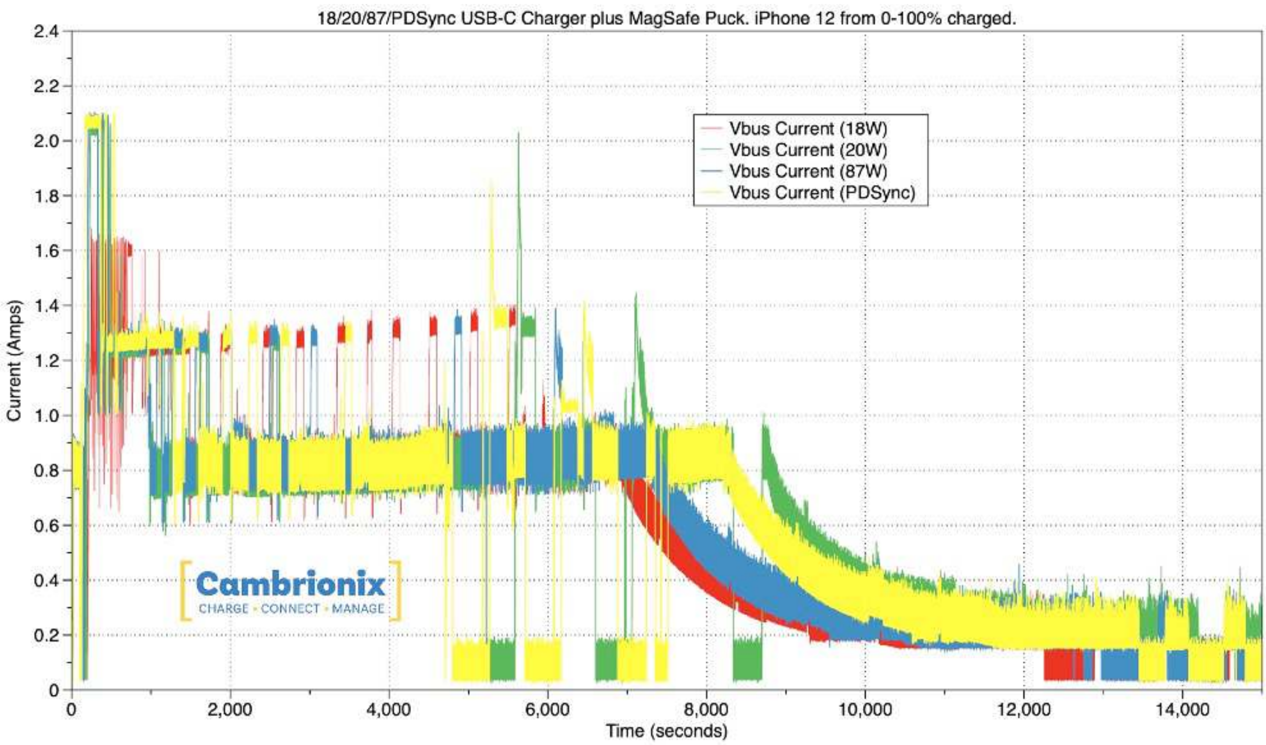
Cambrionix PDSync 60W USB-C Charger:

The iPhone shows as 100% charged after 3.7hrs and the MagSafe Charger accepts 9V at 3Amp (27W). Ambient temp was 22deg C. The current profile is similar to the Apple 20W USB-C charger.



Charging current profiles from all chargers:

The graph below shows all previous data overlaid using the same X and Y scale. It's a little hard to interpret but it does show just how close the four USB-C chargers are in terms of operation and the race to 100%. All chargers tested get the iPhone 12 from 0-100% within around 30mins of each other at an ambient temperature of 22deg C (the controlled temperature in my kitchen!).



Initial thoughts on the data:

What I believe I've done is present some basic comparison data to give a little more insight into what happens to the charging current when a MagSafe Charger is used with an Apple or non-Apple USB-C Power Delivery charger and an iPhone 12.
I don't have detailed data regarding the decisions made within the iPhone and/or the MagSafe Charger when it comes to manipulating the battery charging speed although Apple do offer the caveat that charging speed may vary depending on System Activity and Temperature: https://support.apple.com/en-gb/HT211829

These caveats from Apple make perfect sense from a technical point of view for the following reasons:

- Li-Ion batteries can be irreparably damaged if charged above or below a specific temperature range. Apple provides guidance on charging Li-Ion batteries on their website and they recommend to not charge the battery when device is operated within an ambient temperature above 35deg C: https://www.apple.com/uk/batteries/maximizing-performance/
- The MagSafe Charger is not made of magical superconductors and does have inefficiencies. These inefficiencies manifest themselves as heat and the generator of this heat is attached, in close proximity, to the rear of the iPhone 12. Think of the MagSafe Charger as a little heater held in place with integrated magnetics next to your battery. This, or any method of charging, will always generate heat, this is just a law of physics.
- System Activity generates heat. Ever played an iOS game and felt your device get a little warmer than normal? That's due to a lot of system activity. More activity and information pushed around, more heat - again, this is just physics and can't be avoided.
- Charging a battery of any type causes the battery, and its charging electronics, to heat up.
- Things that are hot take time to cool, things that are cool take time to heat up. Changes to the charging rate, up or down, will not cause an immediate change in internal temperature.
- Given the choice of a 22deg C office or a 35deg C summer day, your electronics would choose the cooler environment. Prolonged use at elevated temperatures can have a detrimental affect on electronics systems and the temperature of the iPhone case doesn't necessarily give the user any indication of how hot a chip on the internal PCB is! The internal temperature of the iPhone could be a lot higher than what you feel on the outside - especially if you use a case.
- Prematurely aged batteries, due to being charged at elevated temperature and within a warranty period, would cost the OEM money to replace. It's absolutely expected that an OEM like Apple will do whatever they can to prevent in-warranty failure and potential brand-damage.

What I think is going on:

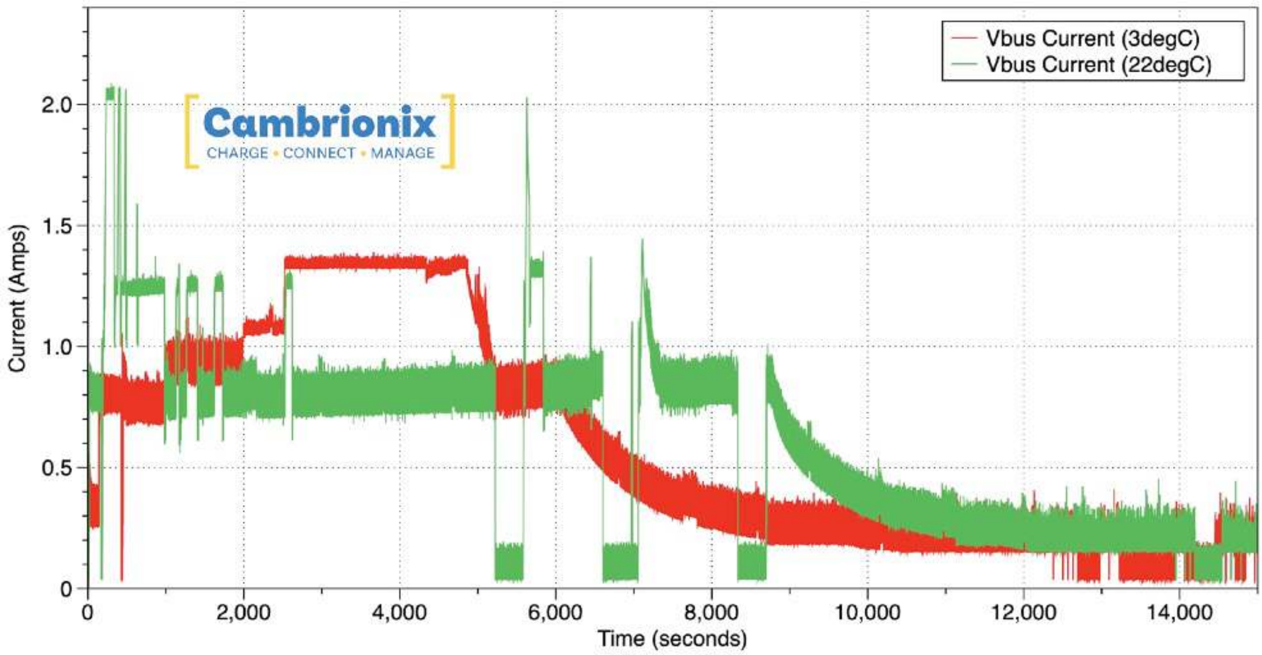
So, if I were to make an educated guess at what's going on within the iPhone and MagSafe Charger, I'd say that there are some clever Apple algorithms which take all of the previous factors into account and either reduce or increase the charging speed in response to these environmental and system factors. I suspect these algorithms may maintain a balance between charging as fast as possible whilst maintaining battery health. I believe there is a big emphasis on temperature.

Charging in the refrigerator:

In order to test the idea that temperature plays a big role in determining charging speed I performed a 0-100% test-run in a household fridge. This isn't the most scientific test but hey, we're all working at home right now so a kitchen-lab will have to do!
The temperature within the fridge was maintained at 3deg C. In order to be sure that the door remained closed during the test, the family was packed off to bed and the test was run overnight.

Other things to note are that the phone was in the same starting-state as with the previous tests and the MagSafe Charger and iPhone 12 both had over 2 hours within the fridge to get to temperature. During these 2 hours the iPhone and MagSafe Charger were not powered up.

Here is the test run from the fridge at 3deg C along with the previous results from 22deg C. The reduced temperature seems to keep the charging current, shown in red, at a higher level for longer.



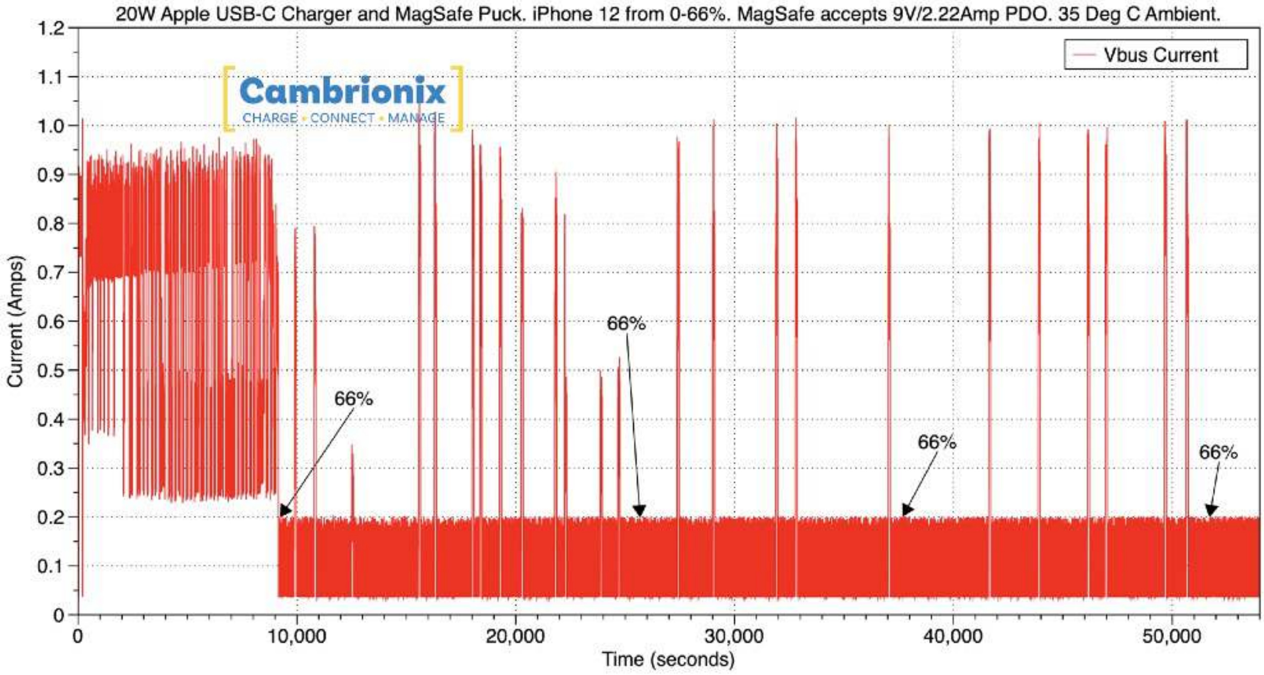
Charging in the oven (don't try this at home, like I did):

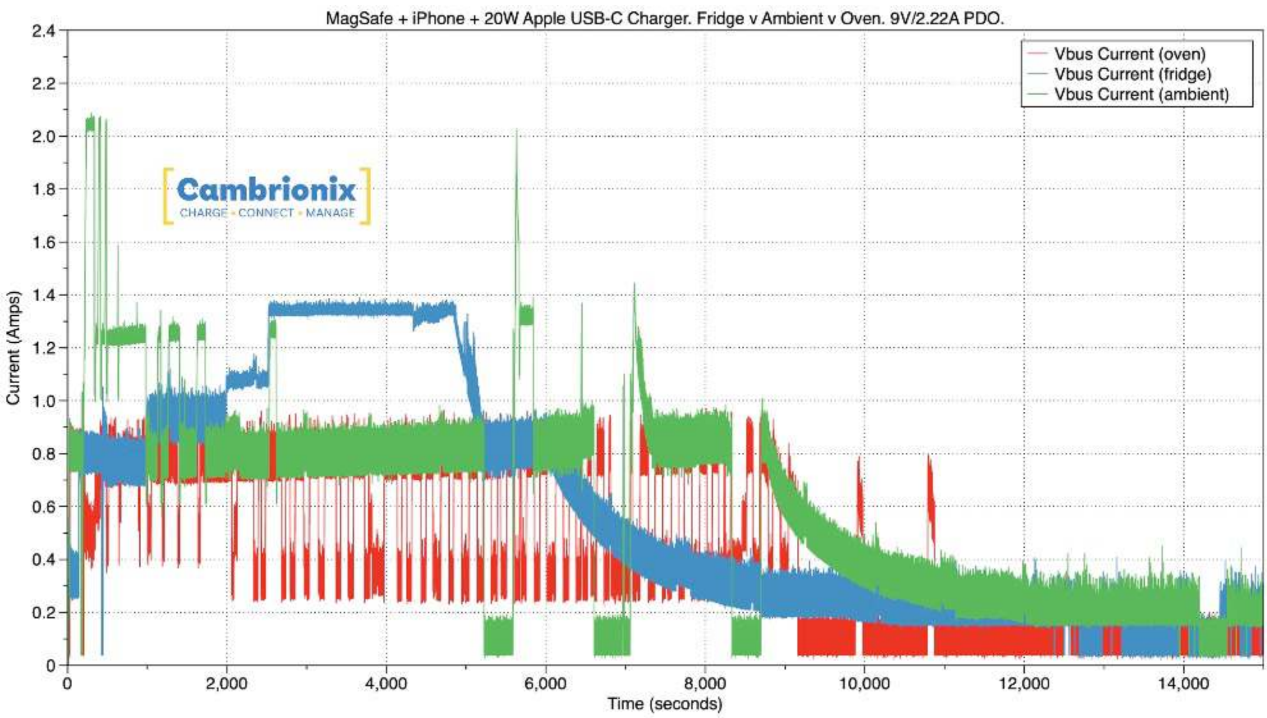
Ok, so it charges better in the fridge, what about the oven?

Lets do a test run at the upper limit of Apples' charging temperature, 35deg C. https://www.apple.com/uk/batteries/maximizing-performance/

This test run performed as expected, poorly.
The iPhone and MagSafe Charger had an hour to get to temperature in the oven and the 20W USB-C charger, laptop etc remained outside of the oven.
To cut a long story quite short, the iPhone 12 never reached 100% charged even after 14hrs. In fact, the phone reached 66% after approx 2.5hrs and then remained at 66% for the duration of the 14hr test run.
Without knowledge of how the iPhone (or MagSafe Charger) increases/decreases charging current based upon temperature all I can speculate is that Apple are adhering to the upper 35deg C limit on battery charging ambient temperature. This is a good thing since it's commonly known that charging in an elevated ambient is bad for batteries.
Somewhere within the recommended ambient operating range of the iPhone and MagSafe Charger there will be a Goldilocks-zone where the temperature is just right and charging is optimised. Much more testing is required in order to find this sweet-spot though.

The first graph below shows the full 14 hour test run data. The second graph shows the fridge, oven and 22deg C data overlaid and trimmed to 15,000 seconds.
We suspect that some form of battery protection was being used by the iPhone due to the elevated temperature.





Conclusions:

The differences in the charging speeds of the various USB-C chargers is minimal and any charger offering 18W or more and supporting USB-C PD2.0 or PD3.0 should, and does, work just fine.

Does temperature have much of an effect on the MagSafe Charger+iPhone 12? Yes it does, and yes it should. Charging your devices within the temperature range recommended by Apple will ensure you get the best performance and longevity from your battery.
Charging on a hot day in an ambient temperature of 35deg C or more makes effective and speedy charging almost impossible.

Whether this is worth clearing your beer fridge for is another matter…

About Cambrionix:

Cambrionix are relied upon by our customers to provide robust, safe and efficient hardware for high-speed data transfer and charging of large-scale mobile device deployments in healthcare, enterprise, education and hospitality environments.
Cambrionix are based in Cambridge, United Kingdom.
www.cambrionix.com