JOURNAL OF
EMERGING INVESTIGATORS

Article

Mapping the electromagnetic field in front of a microwave oven

Angela Xiang[1], Hui Xiang[2]
[1] Portola High School, Irvine, California
[2] UCLA Extension, Los Angeles, California

SUMMARY

There is limited evidence that EMF may have negative health effects on human beings with extended exposure. This study measured the power density and strength of EMF at different distances and directions in front of a microwave oven. Our results showed that the EMF levels are high (≥ 100 mG) at "one arm's length" distance (61 cm) in all directions, although the power density drops to a range of 0.01 – 0.10 mW/cm^2. To achieve a power density of 0.05 mW/cm^2 or less and an EMF level of 25 mG or less, the distance should be at least 91 cm and 122 cm, respectively, away from the microwave oven, especially in the left and front directions. Based on the measurement data, we created exposure maps using precautionary thresholds of 0.05 mW/cm^2 and 25 mG for power density and EMF, respectively. The measurement results help to understand the EMF distribution in front of the microwave oven. The results suggest that one should avoid staying less than 122 cm away from the microwave oven during operation, and that the "one arm's length" distance (61 cm) may not be sufficient due to the high EMF levels. This study helps to promote awareness of the potential health risks associated with microwave ovens.

INTRODUCTION

A microwave oven is a commonly used electronic appliance that heats food by exposing it to microwave radiation generated by a magnetron (1). Microwaves are a form of non-ionizing electromagnetic energy with frequencies ranging between 0.3–300 GHz, which are used extensively in radar (2). In 1945, while developing magnetrons for radar signals, Dr. Percy Spencer discovered that microwaves could heat up food. Based on this observation, the microwave oven was developed and was first marketed in 1946. Today, most American households have microwave ovens in their kitchens. A microwave oven works by passing microwave radiation, usually at a frequency of 2450 MHz, through food. Water, fat, and sugar molecules in the food absorb energy from the microwave beam and become hot. Microwave beams pass through glass, paper, ceramic, or plastic, but metals reflect microwaves, thus not safe to use.

There have been concerns about the potential adverse health effects upon exposure to microwave energy (3–6). The U. S. Food and Drug Administration (FDA) sets an emission limit from microwave ovens so that "the … power density existing in the proximity of the external oven surface shall not exceed 1 mW/cm^2 at any point 5 cm or more from the external surface of the oven, measured prior to acquisition by a purchaser, and, thereafter, 5 mW/cm^2 at any such point" (7). It is known that the microwave radiation dissipates quickly as the distance increases away from the energy source. At "one arm's length" (approximately 61 cm) away from the microwave oven, the power density would drop to approximately 0.05 mW/cm^2, assuming 5 mW/cm^2 at 5 cm from the microwave (8). A study measured the microwave leakage of 106 microwave ovens and found that only one oven exceeded the 5 mW/cm^2 emission limit (9). Though generally considered as safe when used properly, there are some arguments that microwave exposure at much lower levels could be associated with adverse health effects (5, 10).

In addition to direct microwave radiation, the electromagnetic field (EMF) formed around a microwave oven may also be a concern (11). There is limited evidence that accumulated long-term (hours or more) exposure to EMF may have negative health effects on human beings, which increases the risks for neurological disorders, cataracts, and certain types of cancers (12–14). For example, studies have suggested that extended exposure to power frequency magnetic fields greater than 3 mG may result in increased health risks such as childhood leukemia (14, 15). However, the current knowledge is not sufficient to understand the mechanisms by which EMF exposure leads to cancer development. Currently, there are no universally accepted EMF exposure limits. The Environmental Protection Agency (EPA) recommends avoiding long-term exposure to EMF of up to 2.5 mG (12, 16). The short-term exposure level can be up to 25 mG, 10-fold higher than the EPA recommended safe level for long-term exposure (17).

The purpose of this study was to measure the power density and strength of the EMF at different distances around a microwave oven and to verify if "one arm's length" (61 cm) from the microwave oven is a safe distance. We measured microwave power density and EMF levels at various distances from the microwave oven and in different directions in front of the microwave oven. Since the EMF decreases rapidly with the distance from the microwave oven, we hypothesized that at "one arm's length" distance, the measured power density is no more than 0.05 mW/cm^2 and EMF no more than 25 mG.

RESULTS

Power density measurements

To begin to investigate the relative safety at different points from a microwave oven, we first measured power density using a Tri Field Meter at different distances and directions from a microwave oven. Two independent measurements at different dates were performed with the same microwave oven. The overall mean and standard deviations of the two measurements are summarized in **Table 1**. We calculated the mean and standard deviation of the power density measurements and found the values to range from 0.18–0.33 mW/cm^2 at the front outer surface (distance of 0 cm) of the microwave oven (**Table 1**), which is significantly below the emission limit (5 mW/cm^2) set by the FDA. The power density drops quickly with increasing distance from the microwave oven. At "one arm's length" distance (61 cm), the mean power density readings are in the range of 0.01–0.10 mW/cm^2.

We found that the measured power density levels at 61 cm were 0.05 mW/cm^2 or above in the left-45°, up-45°, down-45°, and front directions; and below 0.05 mW/cm^2 in the right, right-45°, and left directions (**Figure 1**).

The power density dissipated more rapidly at both sides (right, right-45°, and left) than at the front of the microwave oven (down-45°, left-45°, front, and up-45°). In particular, it requires 74–94 cm distance at left-45° and down-45° directions for the power density to dissipate to 0.05 mW/cm^2, compared to 61 cm at front and up-45° directions, and 38–41 cm at right, right-45° and left directions (**Figure 2**).

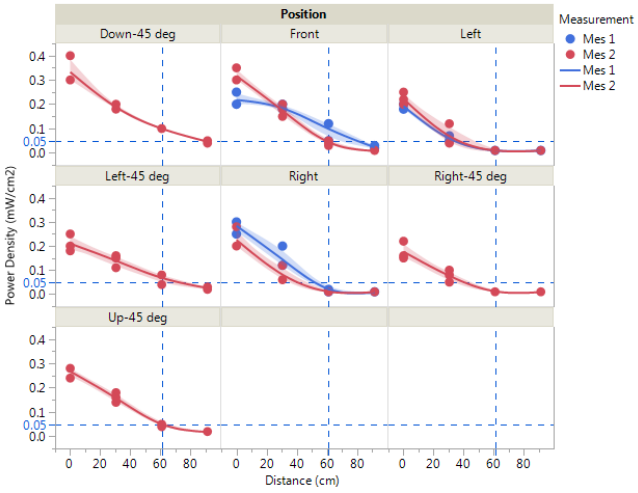

Figure 1: Measured power density at different distances and directions in front of the microwave oven. The graphs illustrate the decreasing trends of the measured power density with the increase of distance from the microwave oven. Two independent measurements, Mes 1 (blue) and Mes 2 (red), were performed with the same microwave oven. The measured power density (dots), regression lines, and 95% confidence areas of regression are illustrated in the graphs, grouped in different directions (horizontal: left, left-45°, front, right-45°, and right; vertical: up-45°, and down-45°). The power density threshold of 0.05 mW/cm^2 and "one arm's length" distance (61 cm) are represented as blue dashed lines.

EMF Measurements

Similar to the measurement of power density, we measured the EMF levels using the Tri Field Meter at different distances and directions in front of a microwave oven. The electric field is 0 V/m at all distances, suggesting that the electric field is shielded completely by the metal pieces of the microwave oven. Thus, the EMF refers to the magnetic field in this study. Two independent measurements of magnetic field levels at different dates were performed with the same microwave oven. The mean magnetic field readings were as high as 100 mG at distance ranges from 61 cm (right) to 104 cm (left-45°) and dropped to approximately 25 mG at distance ranges from 74 cm (right) to 112 cm (left-45°), respectively.

At all directions, at "one arm's length" distance (61 cm), the measured EMF levels were at least 100 mG (**Figure 3**). The EMF levels dissipated more rapidly in the right direction, and more slowly in the left and left-45° directions. To have EMF levels at 25 mG, it requires a distance of 102–112 cm in the left and left-45° directions, respectively, compared to 69 cm in the right direction, and 89–94 cm in other directions.

At the same distance from the surfaces of the microwave oven, the EMF levels were the lowest in the right direction, and were the highest in the left-45° direction. It is clear that at the distance of 61 cm, the measured EMF level is 100 mG or greater at all directions (**Figure 4**). To have an EMF exposure of 25 mG or lower, it requires a distance ranging from 69 cm (right) to 112 cm (left-45°) away from the microwave oven.

Distance from microwave oven (cm)	Power density (mW/cm^2) mean ± std dev						
	Front[a]	Left[a]	Left-45°[b]	Right[a]	Right-45°[b]	Up-45°[b]	Down-45°[b]
0	0.27 ± 0.06	0.21 ± 0.02	0.21 ± 0.04	0.26 ± 0.05	0.18 ± 0.04	0.27 ± 0.02	0.33 ± 0.06
30	0.18 ± 0.02	0.06 ± 0.03	0.14 ± 0.03	0.11 ± 0.05	0.08 ± 0.03	0.16 ± 0.02	0.19 ± 0.01
61	0.07 ± 0.04	0.01 ± 0.00	0.07 ± 0.02	0.01 ± 0.01	0.01 ± 0.00	0.05 ± 0.01	0.10 ± 0.00
91	0.02 ± 0.01	0.01 ± 0.00	0.03 ± 0.01	0.01 ± 0.00	0.01 ± 0.00	0.02 ± 0.00	0.05 ± 0.01

[a]n = 6. [b]n = 3.

Table 1: Data were obtained from Mes 1 and Mes 2. Values of the mean, standard deviation, and number of readings of power density are grouped based on the distance from the microwave oven in each direction. The measured power density values range from 0.18–0.33 mW/cm2. At "one arm's length" distance (61 cm), the mean power density readings are in the range of 0.01–0.10 mW/cm^2.

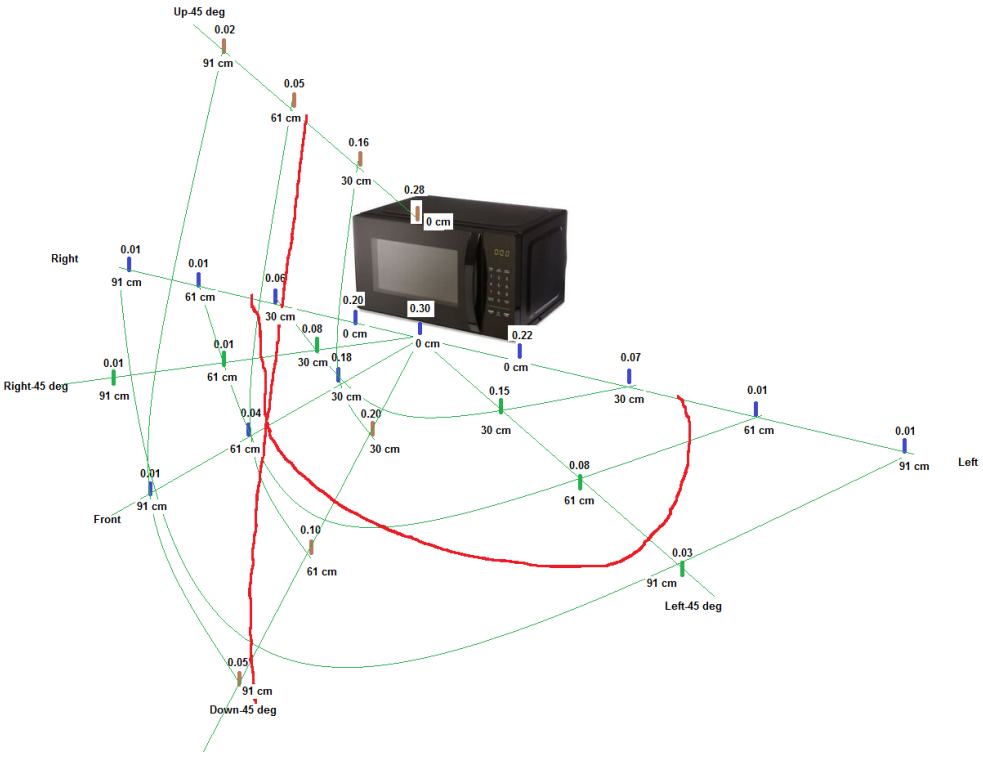

Figure 2: Schematic illustration of the power density distribution in front of the microwave oven. The schematic illustration of the power density distribution on the horizontal and vertical directions in front of a microwave oven. The green lines and curves represent approximate distances (in centimeters) in different directions (horizontal: left, left-45°, front, right-45°, and right; vertical: up-45°, and down-45°); The mean power density (in mW/cm^2, based on Mes 2) and distance are labeled for small bars, which are colored in blue, green, and brown to show different directions; The red lines represent the power density threshold of 0.05 mW/cm^2. It is clear that the power density at "one arm's length" distance (61 cm) in the left-45° and down-45° directions is greater than 0.05 mW/cm^2.

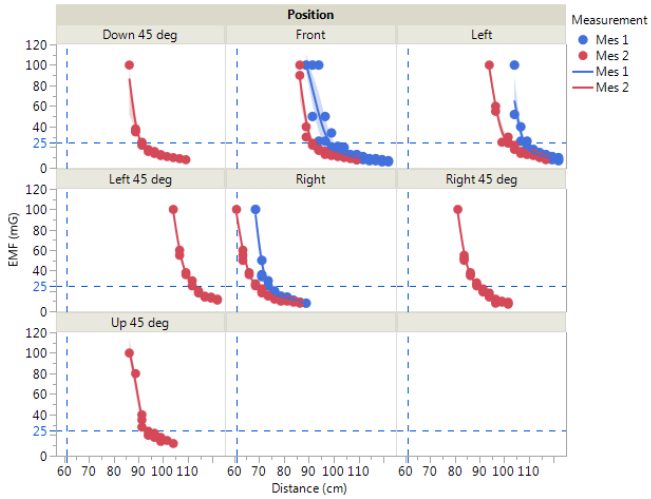

Figure 3: Measured EMF at different distances and directions in front of the microwave oven. The graphs illustrate the decrease of the measured EMF levels with the increase of distance from the microwave oven. Two independent measurements, Mes 1 (blue) and Mes 2 (red), were performed with the same microwave oven. The measured EMF (dots), regression lines, and 95% confidence areas of regression are illustrated in the graphs, grouped in different directions (horizontal: left, left-45°, front, right-45°, and right; vertical: up-45°, and down-45°). The EMF threshold of 25 mG and "one arm's length" distance (61 cm) are represented as blue dashed lines.

DISCUSSION

There have been concerns about the potential health risks that a microwave oven could generate by leakage of microwave radiation (3–6) and exposure to the EMF that forms around the oven (12–14). The microwave radiation decreases quickly as the distance increases away from the energy source. A measurement suggested that the power density dropped to approximately 0.05 mW/cm^2 at the distance of 61 cm from the microwave oven (8), which is 100-fold lower than the emission limit set by the FDA (7). Based on a data from EPA, the EMF drops to approximately 25 mG at the distance of 91 cm away from a microwave oven (3). This is approximately 10-fold higher than the long-term exposure limit set by the EPA.

This study aimed to evaluate the level of power density and EMF at "one arm's length" distance (61 cm) from a microwave oven. We measured the power density and EMF levels at different distances and different directions, namely front, left, left-45°, right, right-45°, up-45°, and down-45°, from a microwave oven. For the purpose of this study, we used the expected levels of 0.05 mW/cm^2 for the power density (8) and 25 mG for the EMF (3), respectively, as precautionary thresholds.

To ensure the accuracy of the measurements, the

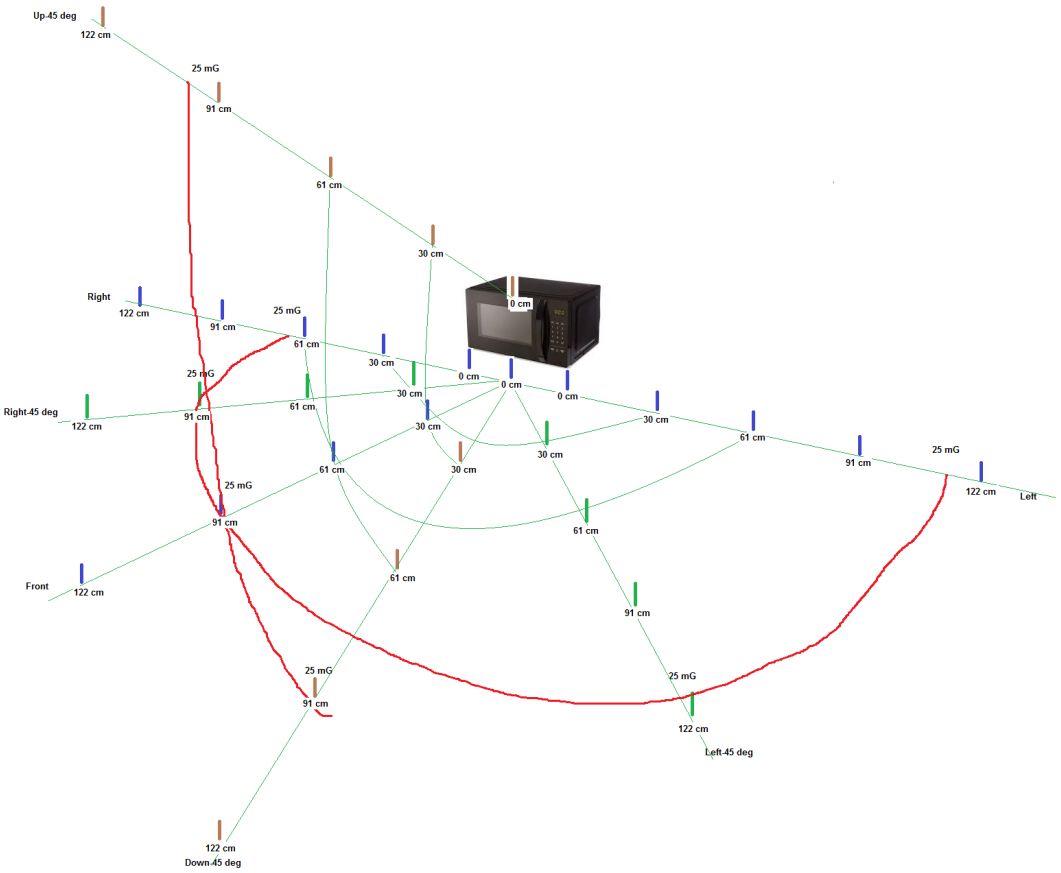

Figure 4: Schematic illustration of the emf distribution in front of the microwave oven. The schematic illustration of the EMF distribution on the horizontal and vertical directions in front of a microwave oven, based on Mes 2. The green lines and curves represent approximate distances (in centimeters) in different directions (horizontal: left, left-45°, front, right-45°, and right; vertical: up-45°, and down-45°); The distance (cm) are labeled for small bars, which are colored in blue, green, and brown to represent different directions; The red lines represent the EMF threshold of 25 mG. It is clear that the magnetic field intensity at "one arm's length" distance (61 cm) in all directions is greater than 25 mG.

contribution of the environment power density and EMF near the microwave need to be assessed. We performed background measurements on both power density and EMF levels at different locations around the microwave oven while the microwave oven was disconnected from power. The readings were quite low, 0 mW/cm^2 for power density and ~1 mG for EMF strength, which was negligible and could be disregarded.

Originally, we planned to measure the microwave oven using different power settings, such as 25%, 50%, and 75% of power, but we found that these low power settings were achieved by alternating between high power and low power, which caused a lot of variations in measurements. Thus, we only used the 100% power setting to run the microwave oven to measure the maximum microwave power density and EMF strength formed around the appliance.

The EMF values were not stable, making it difficult to take readings. Some measured values showed high variability. To reduce the risk of estimation error, we performed multiple measurements and analyzed the measured data by log transformed regressions. Two independent measurements, each with replicate readings, were made at two different dates, with the same microwave oven. The microwave oven is placed in a cabinet that leaves free space only in front of the microwave oven. The EMF field behind the microwave oven was not measured due to the lack of free space.

The results of measured power density and EMF both suggest that at least a distance of 91 cm is required for the power density to decrease to the level of 0.05 mW/cm^2 or below, and a distance of 122 cm is required for the EMF to decrease to the level of 25 mG or below. The measured EMF levels are also higher in left and left-45° directions than the data reported from other studies (11, 12). Based on the measurement data, the power density and EMF exposure maps were created. The results suggest that at the down-45° and left-45° directions it requires longer distance than other directions for power density to dissipate to 0.05 mW/cm^2, so do at the left-45° and left directions for the EMF to dissipate to 25 mG. This is possibly because the magnetron is located on the left side of the microwave oven.

This study helps to understand the distribution of EMF around a typical home appliance and the potential health

risks with exposure to elevated EMF. The results suggest that one should avoid staying less than 122 cm away from the microwave oven during operation, and that the "one arm's length" distance (61 cm) may not be sufficient due to the high EMF levels. Further studies could investigate how the factors such as the age of a microwave oven as well as operating power capacity and voltage affect the surrounding power density and EMF strength. The ultimate question is to understand the mechanism how microwave radiation and EMF adversely affect cell functions and metabolism.

In summary, we measured the power density and EMF in front of a microwave oven at different distances. Based on the measurement data, we created exposure maps using precautionary thresholds of 0.05 mW/cm^2 and 25 mG for power density and EMF, respectively. To obtain an exposure level below the thresholds, it requires a distance of 91–122 cm away from the microwave oven, especially in the left and front directions. The measurement results help to understand the EMF distribution in front of the microwave oven. The results suggest that one should avoid staying less than 122 cm away from the microwave oven during operation , and that the "one arm's length" distance (61 cm) may not be sufficient due to the high EMF levels.

MATERIALS AND METHODS

An LG microwave oven Model LCRT1513ST (Power: 120 V AC, 1500 W; microwave output: 1100 W; frequency: 2450 mHz; oven capacity: 1.5 cu ft; purchased in 2015) was used in this study. A measuring tape was used to measure the distance to the microwave oven at different directions, i.e., front, left, right, left-45°, right-45°, down-45°, and up-45°. A big bowl of water was placed inside the microwave oven, and the microwave was run at 100% power for up to 5 minutes before changing water in the bowl. The values of radio/microwave power density and magnetic field were measured using a Tri Field Meter (model 100 XE) standard version (frequency weighted to 60 Hz; EMF measurement range 0–100 mG, resolution 0.2 mG, with accuracy of ± 20% at 60 Hz; radio/microwave measurement range 0–1 mW/cm^2, resolution 0.01 mW/cm^2, and frequency range 50–3000 mHz) (18). Multiple readings were taken at different distances along the measuring tape at each direction. Two independent measurements, namely Mes 1 and Mes 2, on the same microwave oven were performed on two different dates.

The measured data were entered into JMP data tables and analyzed using JMP software (Version 14) (SAS, Cary, NC). The statistical analysis include mean, standard deviation, 95% confidence interval, regression analysis. The graphs were made using JMP Graph Builder to illustrate the measured microwave power density and magnetic field intensity along the different distances. Schematic exposure graphs were made to illustrate the distances with the precautionary thresholds of power density at 0.05 mW/cm^2 and EMF at 25 mG, respectively.

Received: April 14, 2019
Accepted: July 31, 2019
Published: September 21, 2019

REFERENCES

1. Woodford, Chris. "Microwave ovens: How do they work?" *Explain That Stuff*, 03 May 2018, http://www.explainthatstuff.com/microwaveovens.html.
2. Ackerman, Evan. "A Brief History of the Microwave Oven." *IEEE Spectrum: Technology, Engineering, and Science News*, IEEE Spectrum, 30 Sept. 2016, http://spectrum.ieee.org/geek-life/history/a-brief-history-of-the-microwave-oven.
3. Rifai, Awn B., and Majed A. Hakami. "Health Hazards of Electromagnetic Radiation." *Journal of Biosciences & Medicines*, 28 Oct. 2014. Scientific Research Publishing, http://www.scirp.org/html/50957.html.
4. Panait, Diana E. et al. "Electromagnetic Pollution of the Environment Due Leakage." *Material Plastice*, vol. 56, no. 1, 2019, pp. 82–86, http://www.revmaterialeplastice.ro/pdf/17%20PANAIT%20D%201%2019.pdf.
5. Chauhan, Parul, et al. "Microwave Radiation (2.45 GHz)-induced Oxidative Stress: Whole-body Exposure Effect on Histopathology of Wistar Rats." *Electromagnetic Biology and Medicine*, vol. 36, no. 1, 2016, pp. 20–30, https://www.ncbi.nlm.nih.gov/pubmed/27362544.
6. Hao, Yan-Hui, et al. "Effects of microwave radiation on brain energy metabolism and related mechanisms." *Military Medical Research*, vol. 2, no. 4, 2015, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4440565/pdf/40779_2015_Article_33.pdf7.
7. Food and Drug Administrations. "21 CFR 1030 - Performance Standard for Microwave and Radio Frequency Emitting Products." *Accessdata.fda.gov*, http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?CFRPart=1030.
8. Mqaseem6 Follow. "Microwave Oven." *LinkedIn SlideShare*. 29 Apr. 2015, http://www.slideshare.net/mqaseem6/microwave-oven-47562053.
9. Alhekail, Z.O. "Electromagnetic Radiation from Microwave Ovens." *Journal of Radiological Protection*, vol. 21, no. 3, September 2001, pp. 251–258, https://www.ncbi.nlm.nih.gov/pubmed/11594651.
10. Pockett, Susan "Conflicts of Interest and Misleading Statements in Official Reports about the Health Consequences of Radiofrequency Radiation and Some New Measurements of Exposure Levels." *Magnetochemistry*, vol. 5, no. 31, 2019, https://doi.org/10.3390/magnetochemistry5020031.
11. "What Are Electromagnetic Fields?" *World Health Organization*, 04 Aug. 2016, http://www.who.int/peh-emf/about/WhatisEMF/en/index1.html.
12. Levitt, B. Blake. *Electromagnetic Fields: A Consumer's Guide to the Issue and How to Protect Ourselves*. Lincoln, NE: iUniverse, Inc., 2007.

13. Pall, Martin L. "Microwave Frequency Electromagnetic Fields (EMFs) Produce Widespread Neuropsychiatric Effects Including Depression." *Journal of Chemical Neuroanatomy*, vol. 75, part B, September 2016, pp. 43–51, https://doi.org/10.1016/j.jchemneu.2015.08.001.
14. "Electromagnetic Fields and Cancer." *National Cancer Institute*, www.cancer.gov/about-cancer/causes-prevention/risk/radiation/electromagnetic-fields-fact-sheet.
15. Kundi, Michael "EMFs and Childhood Leukemia." *Environmental Health Perspectives*, vol. 115, no. 8, August 2007, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1940086/.
16. "EMFs in the Home." *Safe Space Protection*, 2019, www.safespaceprotection.com/emf-health-risks/emf-health-effects/emfs-in-the-home/.
17. "EMF Danger Levels from Appliances in Your Home." *Detox Academy*, 2019, www.nontoxicliving.tips/blog/emf-danger-levels-from-appliances-in-your-home.
18. *Trifield 100XE Meter Model TF100XE Instructions*. AlphaLab, Inc., www.trifield.com/UserFiles/TF100XE%20 2015.pdf.

Copyright: © 2019 Xiang and Xiang. All JEI articles are distributed under the attribution non-commercial, no derivative license (http://creativecommons.org/licenses/by-nc-nd/3.0/). This means that anyone is free to share, copy and distribute an unaltered article for non-commercial purposes provided the original author and source is credited.