Leibniz Universität Hannover

RADIATIVE COOLING DEVICE USING NANOMATERIALS

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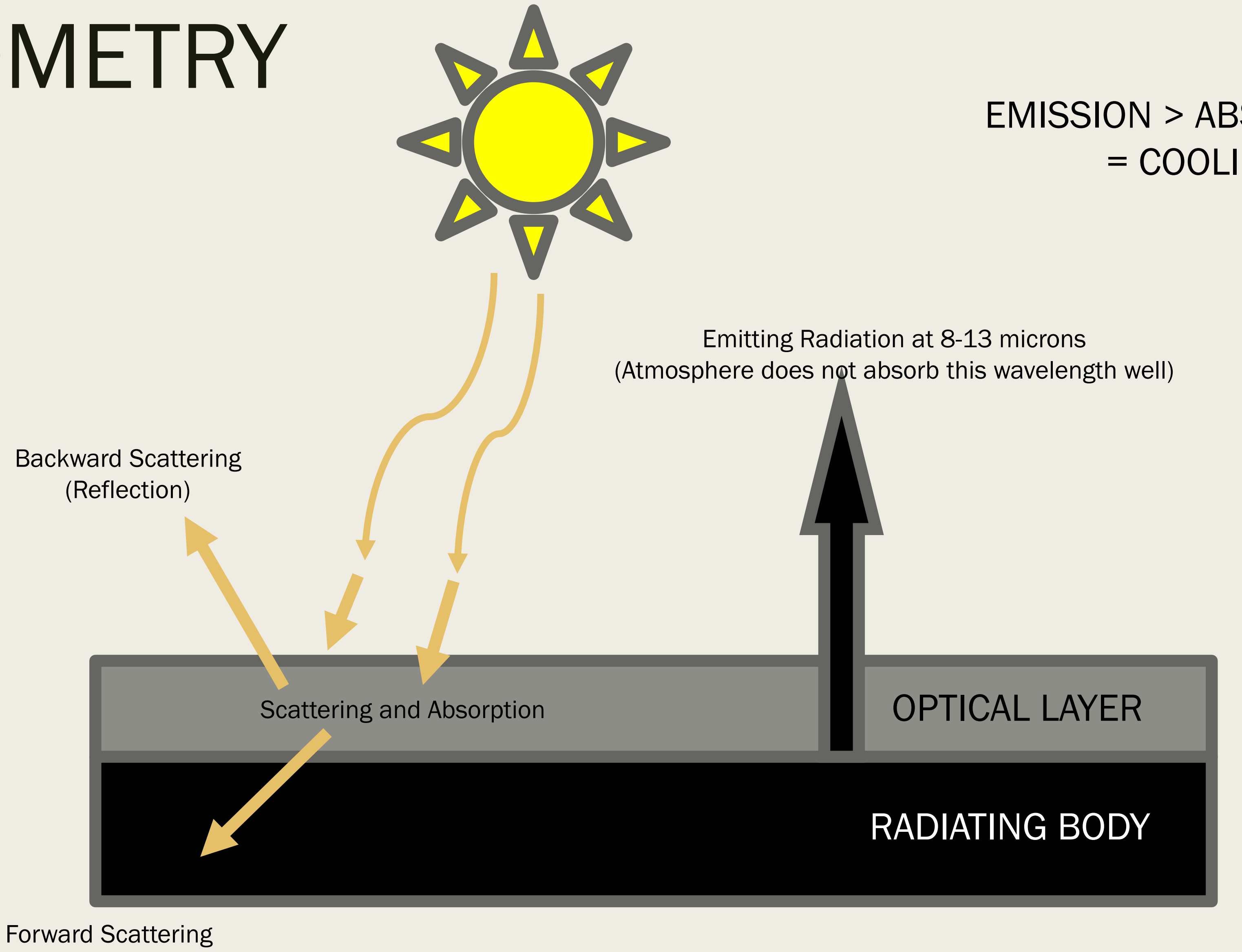
OBJECTIVE

- Simulate a radiative cooling device that emits thermal radiation in the “sky window” wavelength (8-13 micron) while limiting absorbed solar radiation with the use of nanomaterials
- Cooling happens when the emitted radiation is greater than the absorbed radiation
- Hot / ambient temperatures cool directly to space (3 Kelvin)
- Benefits: Minimal to no electrical input for cooling

GEOMETRY

EMISSION > ABSORPTION
= COOLING



RADIATING BODY

- Definition: Any material that will emit radiation at certain wavelengths dependent on temperature
  - *Every body above 0 Kelvin emits thermal radiation*
- In the case of the simulation, the radiating body was assumed to be a black body
- In real life, an external temperature, or heat flux, will be applied to the radiating body

BLACK BODY

- Black body absorbs and emits the same amount of radiation (ideal)
- Planck's Equation (UNITS: W/m^2 / micron)

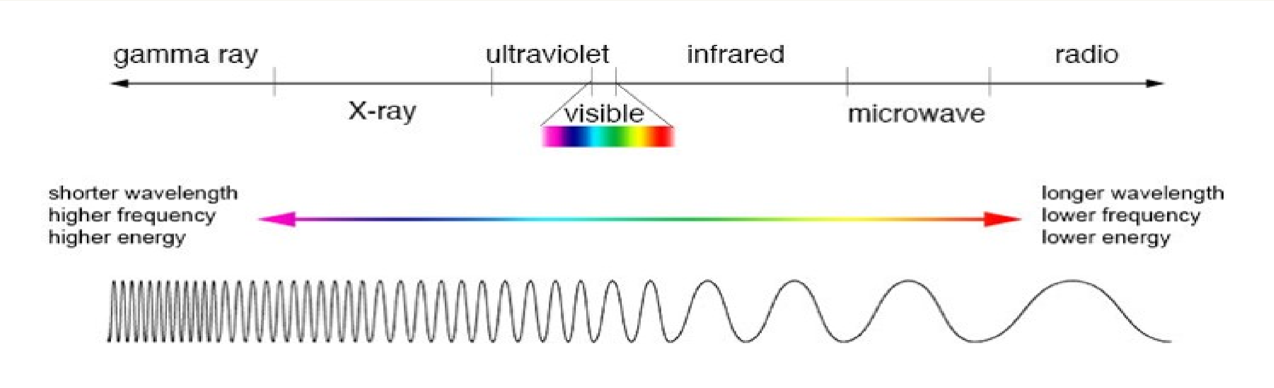
$$I_{Black\ Body}(T,\lambda) = \frac{2\pi hc^2}{n^2\lambda^5\left(e^{\frac{hc}{nkT\lambda}} - 1\right)}$$

h = Planck's Constant
k = Boltzmann's Constant
T = Temperature
n = Refractive Index
c = Speed of light
Lambda = Wavelength

PLANCK’S LAW

- Temperature increases, higher radiation intensity at shorter wavelengths

- Temperature decreases, higher radiation intensity at longer wavelengths



GOAL IS TO EMIT INFRARED RADIATION (HEAT RADIATION) BETWEEN 8-13 MICRONS FROM THE RADIATING BODY

OPTICAL LAYER

- Optical layer is composed of ZnS (Zinc Sulfide) nanoparticles in HDPE (High Density Polyethylene)
- ZnS:
  - *Highly transmissive in the “sky window” (8-13 micron)*

- Other nanoparticles with fair properties for radiative cooling applications:
  - *TiO_2, SiO_2, HfO_2*

NANOMATERIALS

- Definition: Material consisting of nanoparticles
- Each nanomaterial has a different refractive index and volume fraction

REFRACTIVE INDEX

- Definition: How fast light can travel through a material
- Real and Imaginary parts of the refractive index
  - *Real: Disperses wavelengths of light*
    - Refractive index decreases as wavelength increases
  - *Imaginary: Absorption in opaque materials*
- Refractive index is about 2 for ZnS (Varies with wavelength)

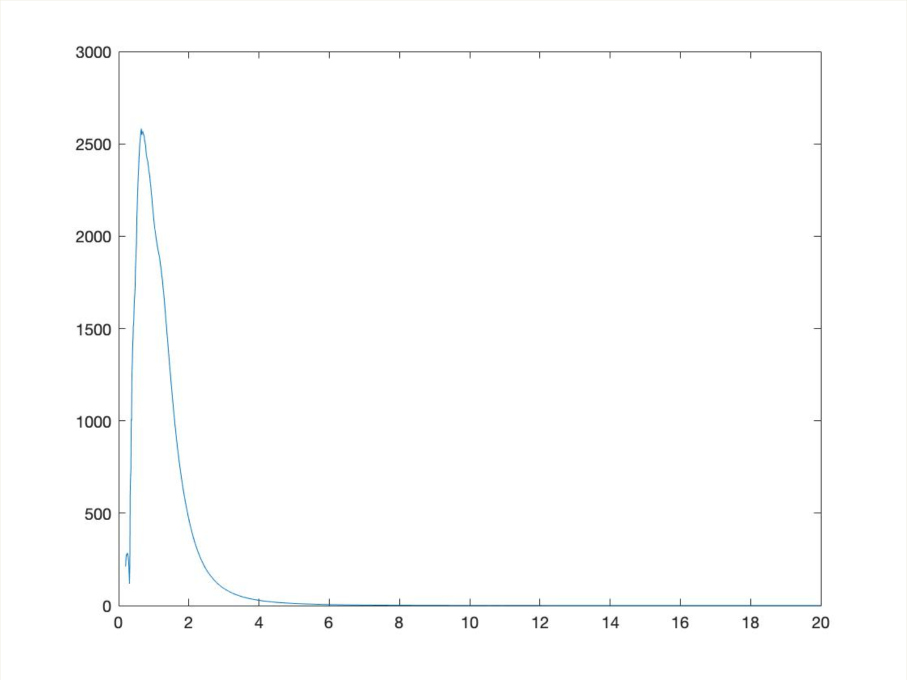
NANOPARTICLES

- Nanoparticles determine scattering and absorption of electromagnetic waves
- Particle size and volume fraction influences scattering and absorption of wavelengths
  - *Larger particles scatter a larger band width of wavelengths*

SCATTERING

- Forward and Backward (Reflection)
- Determined by the real and imaginary refractive index
- The goal is to scatter small wavelengths that solar irradiance projects

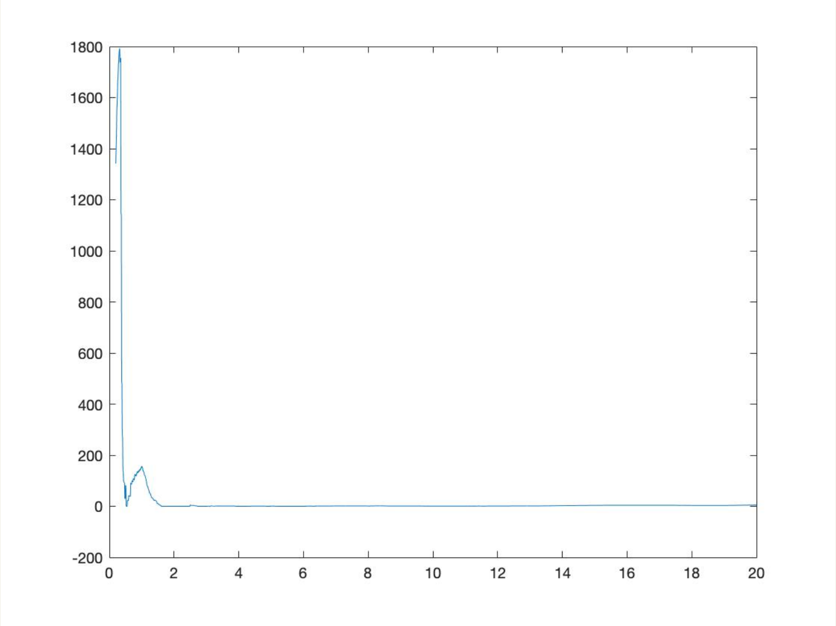
Figure 1: Wavelength vs. Scattering Coefficient



ABSORPTION

- Based off of imaginary refractive index of the nanomaterial
- Based off of the real and imaginary refractive index of nanoparticles
- MATLAB function had high values for absorption
  - *This means no radiation was being transmitted through the optical layer*
  - *Used average absorption coefficient (20 m^-1 @ 10.6 microns)*

Figure 2: Wavelength vs. Absorption Coefficient

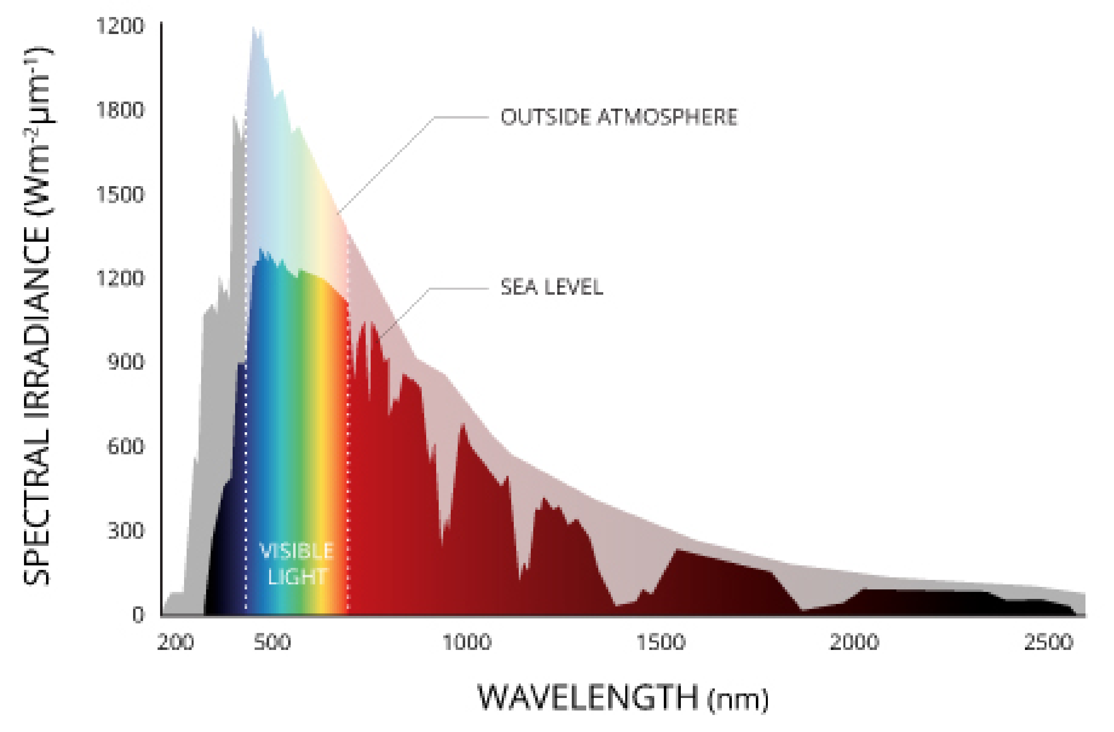


PROGRAMS USED

- MATLAB
  - *Scattering and Absorption functions*
- Ansys CFX
  - *Monte Carlo Radiation Method*
    - Define wavelengths being simulated
      - *Whole spectrum (.2 - 1000 micron)*
      - *Interested in (8 – 13 micron)*
    - Based on number of histories (5,000,000 histories)

SOLAR IRRADIATION

- Amount of electromagnetic radiation experienced, on average, from the sun



OTHER EQUATIONS

- COOLING POWER EQUATION

$$P_{Cooling} = P_{emission\ from\ black\ body} - P_{absorbed\ solar\ irradiation} - P_{other\ heat\ losses}$$

  - *(Other heat losses: Convection, or conduction, external factors)*

- Absorption + Transmission + Reflection = 1
  - *Applies to the waves traveling through the optical layer*

RESULTS (Optical Analysis)

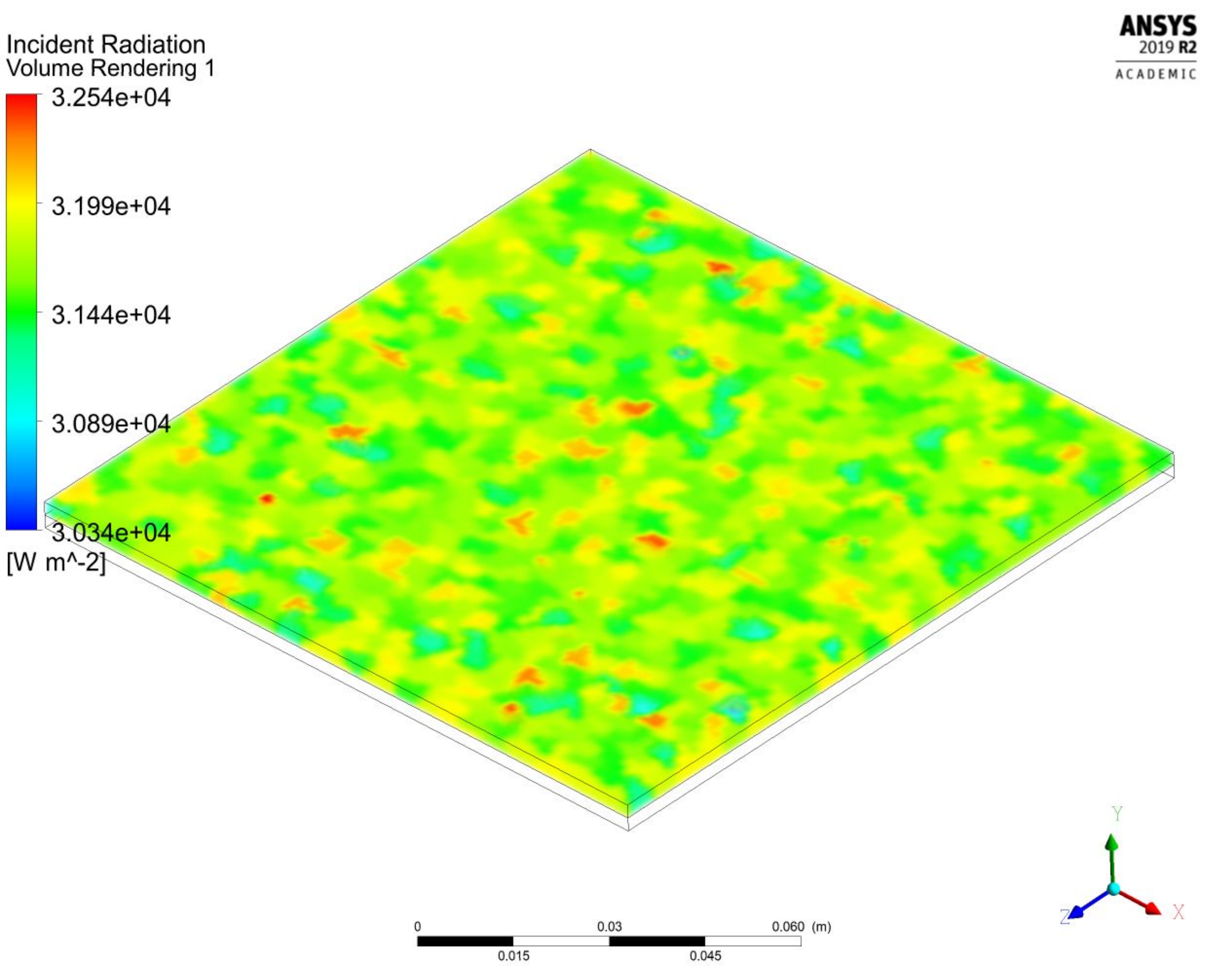


Figure 3: Total Incident Radiation in the Optical Layer when the Radiating Body was at Temperature 295 Kelvin

The optical properties (Scattering and Absorption) produce a non-uniform display of Incident Radiation

CONCLUSION

- As particle size increases, scattering increases in small wavelengths
- Total emitted irradiation flux between the wavelengths 8-13 micron is 82.13 Watts
  - *This value might be higher due to the average absorption coefficient*
  - *Value was calculated in Ansys Post Simulation*
- As long as solar irradiation coming into the system is less than what is emitted there will be cooling
  - *This is determined by the properties of the nanomaterial*

FUTURE WORK / IMPROVEMENTS

- Adjust MATLAB code to simulate absorption accurately at each wavelength
- Couple optical analysis, thermal analysis, and solar irradiance analysis in Ansys CFX
- Obtain experimental values for real materials and use raw data in simulation

CHALLENGES

- Learning Ansys CFX, MATLAB, and Heat Transfer
  - *Steep learning curve with set backs*
- Coupling thermal and optical properties of the device in Ansys CFX
  - *This would simulate cooling effect*
- Obtaining raw data in papers and on the internet
- Getting a thermal analysis result
  - *Ran out of time*

CHALLENGES WITH ANSYS

- Having a quality mesh for radiation simulation
- Defining the Planck equation at the boundary
- Monte Carlo method was not working when the optical layer was a solid
  - *Simulate optical layer as a liquid with high viscosity*
- Keeping the optical layer at 0 Kelvin
  - *Not emitting any radiation*
  - *This also made the energy equation not valid; therefore, no thermal results*

RESOURCES

Heat and Mass Transfer, Karl Stephan and Hans Dieter Baehr. Second Edition

Nanoparticle embedded double-layer coating for daytime radiative cooling, Zhifeng Huang and Xiulin Ruan

Radiation and Energetic Analysis of Nanofluid Based Volumetric Absorbers for Concentrated Solar Power, Jan Rudolf Eggers, Eckart Matthias Lange, and Stephan Kabelac

Radiative Heat Transfer, Michael F. Modest. Third Edition

Wavelength Selective Cover for Sub-Ambient Passive Radiative Cooling, Hannah Kim and Andrej Lenert

https://refractiveindex.info/?shelf=organic&book=polyethylene&page=Smith

https://refractiveindex.info/?shelf=main&book=ZnS&page=Querry

http://www.iiviinfrared.com/Optical-Materials/zns.html

http://www.iiviinfrared.com/Optical-Materials/znsms.html

DEUTSCHLAND

My German Summer

By: Owen Jarl

PLACES VISITED IN GERMANY

- Hannover
- Hamelin
- Hamburg
- Norderney
- Berlin
- Wolfenbüttel

PLACES VISITED IN EUROPE

- Amsterdam, Netherlands

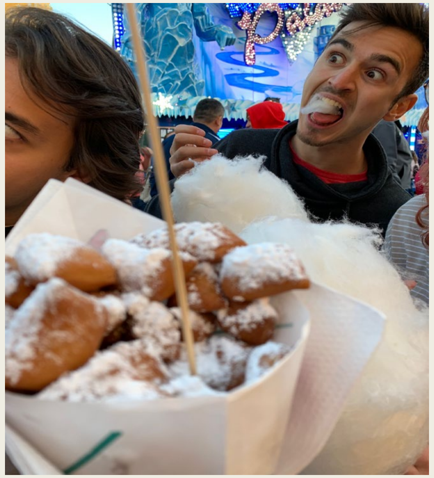
DIFFERENCES (USA AND GERMANY)

- Public transportation is so easy and so common in Germany
- People walk everywhere in Germany and seem to have better relaxing habits (more outdoor activities)
- Three ingredients in beer
- Saying “Bon Appetite” before eating food
- Graffiti
- Smoking
- Knocking on the desk after a presentation
- Making food for celebration of a thesis being completed

THE GOOD EXPERIENCES

- Traveling is so easy around central Europe and in Germany
- Meeting new people that I could interact with everyday and not just meet once
- Learning who I am as an individual being on my own for so long
- Challenging myself in the institute
- Pommes und mayo <3

THE CHALLENGES



- Not having cell phone service or a car
- Nothing open on Sunday makes it harder to do things without planning ahead
- Paying to use the bathroom or to get water
- Keyboard on the computer made it hard to type in the institute
- Not being able to speak German

WHAT IS NEXT?

- Munich, Germany
- Innsbruck, Austria
- Salzburg, Austria
- Prague, Czech Republic
- Kraków, Poland
- Frankfurt, Germany

BACK TO MICHIGAN STATE TO FINISH THE LAST YEAR OF MY UNDERGRAD!


Norderney
Hamburg
Hannover
Amsterdam
Wolfenbüttel
Berlin
Hamelin
Kraków
Frankfurt
Prague
Munich
Salzburg
Innsbruck

THANKS FOR EVERYTHING :)