Add Constexpr Modifiers to Functions to_chars and from_chars for Integral Types in <charconv> Header

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1.1 Introduction and Motivation

There is currently no standard way to make conversion between numbers and strings *at compile time*.

`std::to_chars` and `std::from_chars` are fundamental blocks for parsing and formatting being locale-independent and non-throwing without memory allocation, so they look like natural candidates for constexpr string conversions. The paper proposes to make `std::to_chars` and `std::from_chars` functions for **integral types** usable in constexpr context.

Consider the simple example:

```
constexpr std::optional<int> to_int(std::string_view s) {
    int value;

    if (auto [p, err] = std::from_chars(s.begin(), s.end(), value); err == std::errc{}) {
        return value;
    } else {
        return std::nullopt;
    }
}

static_assert(to_int("42") == 42);
static_assert(to_int("foo") == std::nullopt);
```

We do **not** propose `constexpr` for floating-point overloads, see design choices below.

1.1.1 `constexpr std::format` and reflection

In C++20 `constexpr std::string` was adopted, so we can already build strings at compile-time:

```
static_assert(std::string("Hello, ") + "world" + "!" == "Hello, world");
```

In addition, `std::format` was also adopted in C++20 and now its original author actively proposes various improvements like P2216 for compile-time format string checking. The current proposal is another step towards fully `constexpr std::format` which implies not only format string checking but also compile-time formatting (the only non-`constexpr` dependency of `std::format` is `<charconv>`):

```
static_assert(std::format("Hello, C++{}!", 23) == "Hello, C++23!");
```

This can be very useful in context of reflection, i.e. to generate unique member names:

```
// consteval function
for (std::size_t i = 0; i < sizeof...(Ts); i++) {
    std::string member_name = std::format("member_{}", i);
}
```

1.1.2 No standard way to parse integer from string at compile-time

There are too many ways to convert string-like object to number - `atol`, `sscanf`, `stoi`, `strto*l`, `istream` and the best C++17 alternative - `from_chars`. However, none of them are `constexpr`. This leads to numerous hand-made `constexpr int parse_int(const char* str)` or `template <char...> constexpr int operator"" _foo()` in various libraries:

— `boost::multiprecision` and similar examples with `constexpr` user-defined literals for *my-big-integer-type* construction at compile-time.
— `boost::metaparse` — *yet another* `template <> struct digit_to_int_c<'0'> : boost::mpl::int_<0> {};`

— lexy — parser combinator library with manually written constexpr std::from_chars equivalent for integers (any radix, overflow checks).
— ctre (compile time regular expressions) — number parsing is an important part of regex pattern processing (ctre::pcre_actions::hexdec).

1.2 Design Decisions

The discussion is based on the implementation of to_chars and from_chars from Microsoft/STL, because it has full support of <charconv>.

During testing, the following changes were made to the original algorithm to make the implementation possible:

— Add constexpr modifiers to all functions
— Replace internal assert-like macro with simple assert (_Adl_verify_range, _STL_ASSERT, _STL_INTERNAL_CHECK)
— Replace static constexpr variables inside function scope with constexpr
— Replace std::memcpy, std::memmove, std::memset with constexpr equivalents: third_party::trivial_copy,third_pa
third_party::trivial_fill. To keep performance in a real implementation, one should use std::is_constant_evaluated

1.2.1 Testing

All the corresponding tests were *constexprified* and checked at compile-time and run-time. The modified version passes full set tests from Microsoft/STL test.

1.2.2 Floating-point

std::from_chars/std::to_chars are probably the most difficult to implement parts of a standard library. As of January 2021, only one of the three major implementations has full support of P0067R5:

Vendor	<charconv> support (according to cppreference.com)
libstdc++	no floating-point std::to_chars
libc++	no floating-point std::from_chars/std::to_chars
MS STL	full support

So at least for now we don't propose constexpr for floating-point overloads.

1.2.3 Other implementations

Check of implementation libc++, the following changes were made to the original algorithm to make the implementation possible:

— Move utils functions from charconv.cpp to charconv header
— Replace std::memcpy, std::memmove with constexpr equivalents: third_party::trivial_copy,third_party::trivial
or bit_cast
— Replace std::log2f with constexpr equivalents

Quick check of implementation libstdc++, showed that there are no blocking changes for implementation either.

1.3 Conclusions

to_chars and from_chars are basic building blocks for string conversions, so marking them constexpr provides a standard way for compile-time parsing and formatting.

1.4 Proposed Changes relative to N4868

All the additions to the Standard are marked with green.

1.4.1 Modifications to "20.19.1 Header <charconv> synopsis" [charconv.syn]

```
// 20.19.3, primitive numerical input conversion
struct from_chars_result {
  const char* ptr;
  errc ec;
  friend bool operator==(const from_chars_result&, const from_chars_result&) = default;
};

constexpr to_chars_result to_chars(char* first, char* last, see below value, int base = 10);
to_chars_result to_chars(char* first, char* last, bool value, int base = 10) = delete;

to_chars_result to_chars(char* first, char* last, float value);
to_chars_result to_chars(char* first, char* last, double value);
to_chars_result to_chars(char* first, char* last, long double value);

to_chars_result to_chars(char* first, char* last, float value, chars_format fmt);
to_chars_result to_chars(char* first, char* last, double value, chars_format fmt);
to_chars_result to_chars(char* first, char* last, long double value, chars_format fmt);

to_chars_result to_chars(char* first, char* last, float value,
                         chars_format fmt, int precision);
to_chars_result to_chars(char* first, char* last, double value,
                         chars_format fmt, int precision);
to_chars_result to_chars(char* first, char* last, long double value,
                         chars_format fmt, int precision);

// 20.19.3, primitive numerical input conversion
struct from_chars_result {
  const char* ptr;
  errc ec;
  friend bool operator==(const from_chars_result&, const from_chars_result&) = default;
};

constexpr from_chars_result from_chars(const char* first, const char* last,
                                       see below & value, int base = 10);

from_chars_result from_chars(const char* first, const char* last, float& value,
                             chars_format fmt = chars_format::general);
from_chars_result from_chars(const char* first, const char* last, double& value,
                             chars_format fmt = chars_format::general);
from_chars_result from_chars(const char* first, const char* last, long double& value,
                             chars_format fmt = chars_format::general);
```

1.4.2 Modifications to "20.19.2 Primitive numeric output conversion" [charconv.to.chars]

```
constexpr to_chars_result to_chars(char* first, char* last, see below value, int base = 10);
```

1.4.3 Modifications to "20.19.3 Primitive numeric input conversion" [charconv.from.chars]

```
constexpr from_chars_result from_chars(const char* first, const char* last,
                                       see below & value, int base = 10);
```

1.4.4 Modifications to "17.3.2 Header <version> synopsis" [version.syn]

```
+ #define __cpp_lib_constexpr_charconv _DATE OF ADOPTION_ // also in <charconv>
```

1.5 Revision History

Revision 2: * Add missing modifications to [charconv.to.chars]/[charconv.from.chars] * Add missing comment to feature-test macro

Revision 1:

- Update the wording relative to [N4868]
- Used `__cpp_lib_constexpr_charconv` as feature macro

Revision 0:

- Initial proposal
- Mailing list review Summary
  - No implementation concerns for libstdc++, should be possible for libc++ too
  - Please put the wording in code font
  - Use `__cpp_lib_constexpr_charconv` as feature macro

1.6 Acknowledgements

Thanks to Antony Polukhin for reviewing the paper and providing valuable feedback.

1.7 References

- [N4868] Working Draft, Standard for Programming Language C++. Available online at https://github.com/cplusplus/draft/raw/master/papers/n4868.pdf
- Microsoft's C++ Standard Library https://github.com/microsoft/STL, commit 2b4cf99c0441766374975182942810464 39a
- Proof of concept for `to_chars` and `from_chars` functions for integral types https://github.com/Neargye/charconv-constexpr-proposal/tree/integral
- [P0067R5] Elementary string conversions http://www.open-std.org/jtc1/sc22/wg21/docs/papers/2016/p0067r5.html
- [P2216R2] `std::format` improvements http://www.open-std.org/jtc1/sc22/wg21/docs/papers/2021/p2216r2.html